STATENS VÄXTSKYDDSANSTALT · MEDDELANDEN 12:83
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Studies on some major storage pests in Sweden, with special reference to their cold resistance

Studier över viktigare förrådsskadedjur i Sverige med avseende främst på motståndskraften mot låg temperatur

BY
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Med svensk sammanfattning

With 6 Figures and 12 Tables

STOCKHOLM 1961

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Emil Kihlströms Tryckeri AB Stockholm 1961

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Introduction

Cosmopolitan storage pests are characterized generally by their sensitivity and limited resistance to cold, although the various species display considerable differences in these respects; cf. reports by COTTON 1956, DENDY & ELKINGTON 1920, MANSBRIDGE 1936, SOLOMON & ADAMSON 1955. The winter months thus constitute a more or less critical period for these pests, depending on the prevailing climate and their resistance, and this applies especially to pests in grain and similar products which, as is known, are usually stored in unheated buildings. The effect of a fall in temperature on the activity and continued existence of different pests constitutes an object of research which is of practical importance in several respects. For example, a sound basis can be worked out for regulating temperatures with the object of preventing attack by pests or destroying them.

In all the expansive northern parts of Sweden the winters are so severe that storage pests do not generally create any problem in unheated buildings. Also in other parts of the country the climatic conditions prevailing during winter are such that vulnerable stored supplies normally assume or may be made to assume a comparatively low temperature. This is illustrated by the following air-temperatures (normal temperature 1901—1930) measured in Stockholm and Ystad, the southernmost town of Sweden.

	Stockholm	Ystad
October	6.4°C	8.8°C
November	1.6	4.5
December	—1.3	1.9
January	—2.5	0.6
February	—2.6	0,0
March	—0.4	1.8
April	3.6	5.1

Table 1 shows how grain which has been stored in deep layers during the cold season of the year retains its practically constant, low temperature of between 5 and 10° the year round. The following figures, referring to approximately 3,000 tons of wheat and recorded on May 29th, 1956, show that the rise in temperature in a large quantity of grain caused by summer heat occurs only in the outermost layer: air-temperature about 1½ metres above the surface 40°, temperature in the wheat 14° at a depth of 0.25 m, 12.° at a depth of 0.5 and roughly 9° at a depth of 1.5 m and more. In this connection, it should also be mentioned that the temperatures of the free air at different levels in a storage place containing grain can vary greatly. By way of example, in July 1955 the air temperature 10 cms above the top surface of a ridge-shaped wheat store was found to be 24.5°, while the corresponding temperature above the slope of the ridge a few metres lower down was only 15°.

If deep-layer grain, at the time it is stored, has a temperature as low as that given in Table 1, the risk of attack by pests may be considered insignificant. Any existing pests which may be sensitive to cold can be expected to die out more or less completely during the course of the winter months. An exception to this is the grain moth, *Tinea personella,* which, however, in the case of large-scale grain storage may be regarded as a pest of secondary importance, partly in view of its tendency to attack only the surface, partly because of there being no heating and partly because it has proved comparatively easy to combat it effectively.

Among other things proving the im-

Table 1. Temperature, at a depth of 1½—2 metres, in four different parts of wheat in bulk storage

Tabell 1. Temperatur på 1½—2 meters djup i fyra olika delar av ett löst lagrat veteparti.

Year and month *År och månad*	Temperature, °C. *Temperatur*			
	I.	II.	III.	IV.
1956 December	5	2	4	7
1957 January	6	2	4	7
February	6	1	3	7
March	6	0	3	7
April	6	5	3	7
May	7	5	5	7
June	8	8	7	7
July	9	7	7	8
August	8	11	8	9
September	7	11	10	8
October	7	9	10	8
November	8	9	8	7
December	8	5	8	8
1958 January	8	5	8	8
February	8	5	6	8
March	7	9	7	6
April	8	6	5	8
May	8	3	6	7
June	6	8	7	9
July	10	8	6	10
August	9	9	10	9
September	13	14	10	9
October	9	11	9	9
November	9	10	8	9
December	9	6	8	9
1959 January	9	5	10	9
February	8	7	8	7
March	9	9	8	9

portance of the temperature of the vulnerable product when stored, with regard to the activity of different pests are the experiences acquired in connection with the large-scale, prolonged storage of grain for bread (wheat and rye) and of certain imported fodder, oil cakes in particular, which is practised in Sweden for emergency purposes and other reasons. The minimum storage time is normally three years. The grain, most of which is produced in Sweden, is dried before being stored to a water content of 13% at the highest. It is stored mainly in bulk in 3—10-meter deep mounds and in storage places of various types. The individual stores of grain, which vary in size between approximately 2,000 and 10,000 tons, are composed of a mixture of lots from several different firms dealing in grain.

In cases where for various reasons it has been necessary to put grain into prolonged storage at a time of the year when the temperature of the product is comparatively high, numerous cases of infestation, often quite serious, have been observed to be in progress either a short or a longer time after. In addition to *Laemophloeus ferrugineus,* several other species of heat-requiring insects were found to have caused most damage to the grain stores, and these were insects which are not normally capable of surviving the winter in well cooled grain, such as *Sitophilus oryzae, Rhizopertha dominica* and *Oryzaephilus surinamensis.* Because of the degree of heating which always accompanies attacks by the pests in question, these latter have been capable of mass reproduction even during the coldest winter months.

A method whereby the sensitivity to low temperatures of the insect species in question is utilized for the purpose of destroying them is now being successfully applied in Sweden. It is adapted from a Russian idea (KOSMINA 1956) and consists of chilling and blowing air through large, affected stores of grain with the aid of special portable units. During the past two years the method has been employed in treating seven heavily infested stores comprising a total of approximately 17,000 tons of wheat and 3,000 tons of rye. A survey of the method describing its application and the results so far achieved is being compiled for publication. Preliminary details are given in the author's paper of 1959.

In the continuation of this present work, the main part is devoted to a report on certain studies made in order to investigate the dependence of various storage pests on the temperature of the

surrounding media, especially their resistance to cold. Other subjects dealt with include their reproduction capacity at great depths in bulk grain and in appearing heating spots with a high temperature (*S. oryzae, Rh. dominica* and others), *O. surinamensis* as a primary pest in stored grain, and weight losses in grain as a result of the occurrence of *Rh. dominica*.

Sitophilus granarius L

It should first be pointed out that, in Sweden, *S. granarius* plays no more important a role as a pest in grain stored over a long period than do other more heat-requiring species such as *S. oryzae* and *Rhizopertha dominica*, or beetles of the *Laemophloeus* and *Oryzaephilus* genera. Although *S. granarius* is often to be found in infested stores, it has very seldom been the dominant species, and in several more serious cases, its presence has been entirely lacking. These circumstances can probably be explained by the following. In a comparatively short time, the temperature in the affected parts, which may rise to 40°C, becomes super-optimal or lethal for *S. granarius*. At the same time, the moisture content of the grain becomes sub-optimal; a drop from the original 13% to between 10 and 12% has been observed regularly in connection with heating caused by pests. The other species have more chance than *S. granarius* of surviving and reproducing rapidly in a warm, dry medium.

Resistance to cold in laboratory experiments

The test insects were reared in wheat with a moisture content of 13.5 ± 0.5%, kept at room temperature and a relative humidity of approximately 70%. In no case has any pronounced insectary stock been used, since all cultures are renewed 2—3 times a year with material consisting of *S. granarius* taken from samples of infested grain from different parts of the country.

All adults used in the individual experiments were of mixed ages, varying between 1 and a maximum of 6 weeks at the beginning of the experiment. During exposure the beetles were placed in an approximately 1-cm. thick layer of wheat kernels in low glass bowls covered with fine wire gauze.

The material used in experiments with eggs was obtained by exposing wheat with a moisture content of 13.5 to 14% at room temperature for egg-laying by 15—30-day-old beetles, roughly 2,000 to every kilogram of wheat. The beetles were removed after 4 days, immediately prior to the preparatory reduction in the temperature of the wheat (see below). During the exposure period the wheat was kept in 4-cm layers in open cardboard boxes, each holding 1.2 kgs of wheat. The same arrangement was employed during experiments with wheat containing all developmental stages. Average samples were taken from the infested wheat lots and kept at room temperature for roughly 2 months for the purpose of determining the number of young adults (= frequency of developmental stages) per unit weight of wheat

Immediately before the actual exposure to cold, both the beetles and infested wheat (including the aforementioned average samples) were subjected to a preparatory reduction in temperature by being kept at between 8 and 10°C. for 48 hours and then at between 4 and 6°C for a further 48 hours. After exposure to cold the material was brought back gradually to room temperature in a similar manner. The thermometers used for the daily temperature readings were kept submerged in the wheat in the test vessels.

The test results are given in Table 2.

The values obtained with regard to the resistance of *S. granarius* are higher than those given in the earlier published works of various authors; cf. report of SOLOMON & ADAMSON 1955, p. 333. Table 3 contains a comparison between the present and corresponding earlier data. According to the former the duration of life for adults can exceed 85 days at 0°C, 70 days at —2° and 40 days at —5°, while BACK & COTTON (1924) give 73, 46 and 33 days respectively as maximum duration of life for *S. granarius* at said temperatures and MATHLEIN (1938) 70, 40 and (at —6°) 25 days.

One of the reasons why experiments of this type give such diverging results is, of course, the impossibility of performing them under identical conditions with regard to the nature of the test material. This is illustrated by, for example, the remarkable degree of sensitivity to cold reported by SOLOMON & ADAMSON in an insectary stock of *S. granarius*. USHATINSKAJA, 1950 b, has

Table 2. Sitophilus granarius. Resistance to cold in laboratory experiments. A = Adults, E = Eggs, L = Larvae, P = Pupae.

Tabell 2. Sitophilus granarius. Motståndskraft mot kyla i laboratorieförsök. A = fullbildade, E = ägg, L = larver, P = puppor.

Developmental-stages *Utvecklingsstadier*	Temperature *Temperatur* °C	Duration of exposure, days *Exponeringstid, dagar*	Number of individuals *Antal testdjur*	Percent dead *Procent döda* 3—5 days *3—5 dagar* after finished exposure *efter avslutad exponering*	Percent dead *Procent döda* 14—16 days *14—16 dagar* after finished exposure *efter avslutad exponering*
E	5 ± 0.5	59	680	100	100
E+L+P		59	640	89	89
E+L+P		100	640	96.9	96.9
A	0 ± 0.5	85	300	99.6	99.6
E		40	700	100	100
E+L+P		40	650	99.1	99.1
E+L+P		50	650	100	100
A	— 2.5 ± 1.5	70	150	82.5	90
A		80	150	98	100
A		90	150	98	100
E		15	75	100	100
E+L+P		20	340	98	98
E+L+P		30	340	100	100
A	— 5 ± 2	30	150	75	95
A		35	150	89.5	96.5[1]
A		40	150	97.3	99.3
A		45	150	98.5	100
E	— 5.5 ± 0.5	10	120	100	100
E+L+P		15	190	100	100
A	— 6.5 ± 0.5	28	200	98.5	98.5
A		33	260	100	100

1 Adults, surviving exposure to —5°, reproduced on normal scale.

1 *Fullbildade skalbaggar, som överlevde exponering vid —5°, fortplantade sig normalt.*

Table 3. Sitophilus granarius. Resistance to cold in laboratory experiments according to various authors.

Tabell 3. Sitophilus granarius. Motståndskraft mot kyla i laboratorieförsök enligt olika auktorer.

Authors *Auktorer*	Temperature *Temperatur* °C	Duration of life, days *Livslängd, dagar*	Notes *Anm.*
Back & Cotton, 1924	0 (— 1, + 2)	72	
Mathlein, 1938	0	70	
Ushatinskaja, 1950 b	0 (± 1)	55—60	Moisture content of wheat 14% *Vetets vattenhalt 14%*
		100 +	„ „ „ „ 18%
Mathlein, 1961	0 (± 0.5)	85 +	„ „ „ „ 13.5%
Back & Cotton, 1924	— 2 (—1, — 4)	46	
Mathlein, 1938	— 2 (± 0.5)	40	
Mathlein, 1961	— 2 (— 1, — 4)	70 +	2% alive after 90 days of exposure, but did not recover. *2 % fortlevande efter 90 dagars exponering, men återhämtade sig ej.*
Back & Cotton, 1924	— 5 (— 4, — 6.5)	33	
Ushantiskaja, 1950 b	— 5 (± 1)	32	Moisture content of wheat 14% *Vetets vattenhalt 14%*
		75	„ „ „ „ 18%
Mathlein, 1961	— 5 (± 2)	40—45	„ „ „ „ 13.5%
Mathlein, 1938	— 6 (± 1)	25	
Mathlein, 1961	— 6.5 (± 1.5)	28—33	

shown that the moisture content of the grain in which *S. granarius* is reared, has a considerable influence on their resistance to low temperatures; cf. Table 3. However, a question of great interest in this connection is whether *S. granarius* has been able to develop local breeds during the course of time with genetically conditioned dissimilarities in regard to resistance. The test results which will later be presented should also show that the resistance is remarkably high in the present Swedish test material.

Exposure to outdoor temperature in winter

A hut belonging to the Swedish Plant Protection Institute was used in these experiments. It is designed in such a way that the inside temperature is always about the same as the outdoor temperature, and it includes such features as walls consisting partly of wire netting. The test material was placed on a platform ½ metre above the surface of the floor and protected against direct sunlight, precipitation and strong winds. In the same way as described earlier, the material was subjected to a gradual reduction in temperature before exposure and a similarly arranged gradual increase in temperature after exposure.

Experiment I. Infested wheat with a 13½ % moisture content, together with adults whose age at the beginning of the experiment varied between 1 and 40 days, were placed in a number of cloth

bags, each being made up to a weight of 1.5 kgs. These, in their turn, were embedded in a rectangular container filled with wheat and with a volume of approximately 45 litres. Two opposite sides of the container were made of masonite and the other two of fine wire gauze. A thermometer was kept permanently embedded in one of the bags of wheat and read daily during the exposure time, while a minimum/maximum thermometer was placed in the immediate vicinity of the container.

The material was placed in the hut on October 8th, 1958. Starting on January 10th, 1959, half of the material was gradually brought to room temperature, and the other half on February 4th, 1959, i.e. after an exposure time of 120 days.

Fig. 1 shows the temperature of the infested wheat during the exposure period. As can be seen, a fairly even fall in temperature occurred during October/November from an original 12° to 0°C. During the remaining 65 days, there was a 16-day period during the latter half of December when the temperature stayed around 0°, but it otherwise remained almost constantly below 0° and only reached this degree on one or two occasions. Four isolated part-periods when the temperature in the wheat was especially low can also be distinguished, viz.:

Part-period	No. of days	Fluctuations between min.	max.
December 11—13	3	—10°C	—7.5°C
January 7—9	3	—6.5	—6
January 15—20	6	—12	—7
January 25—27	3	—9.5	—7

During the last 41 days of the exposure period, the mean temperature in the wheat was —3.7°, and on no occasion did the temperature rise above 0°.

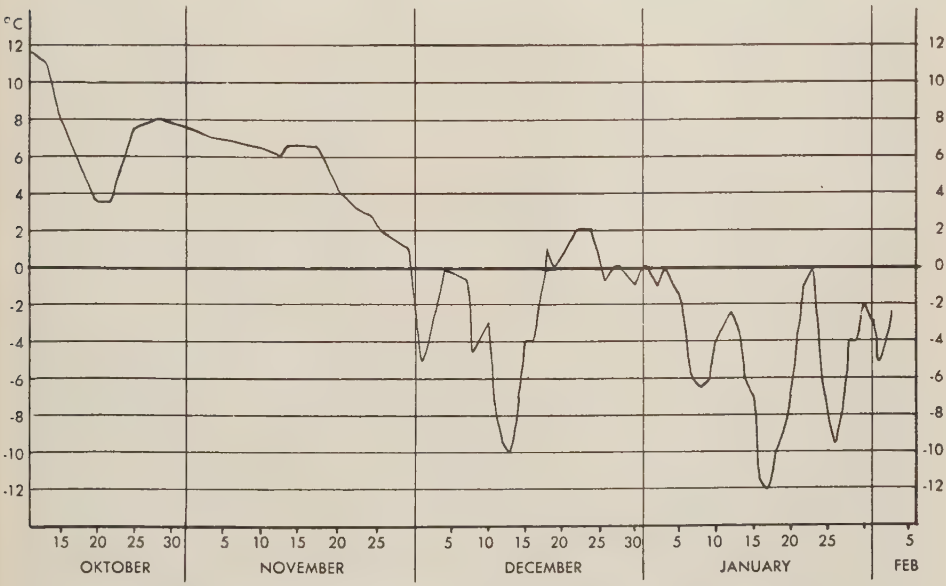

Fig. 1. *Sitophilus granarius.* Temperature of infested wheat during exposure to cold 8.10.1958—4.2.1959; experiment I. p. 8.

Fig. 1. Sitophilus granarius. Temperatur hos angripet vete under exponering för kyla 8.10.1958—4.2.1959; försök I, sid. 8.

At the end of the exposure period on February 4th, 5% of the adults were found to have survived (total number of living and dead was about 1,050). No appreciable degree of mortality could be observed after approximately 1 month at room temperature. The developmental stages in the kernels, on the other hand, were totally dead. At the earlier sampling carried out on January 10th, i.e. after 95 days of exposure, no less than 89% of the 2,000-odd adults in the sample were living, despite the fact that they had been subjected to the very low temperature in the wheat during the first two part-periods mentioned above.

The resistance in *S. granarius* to cold was surprisingly and remarkably high in the experiment described. It exceeded considerably the values obtained in similar experiments previously carried out by the author in 1938 and KIRCHNER in 1940, among others. The slow fall in temperature during the first 7—8 weeks of the exposure period can be assumed to have strengthened the ability of *S. granarius* to endure the more severe cold which later set in; cf. USHATINSKAJA, 1948. The same effect can probably be ascribed to the occasional rise in temperature towards 0°C between the different periods of severe chilling.

Unfortunately, it was not possible to extend the experiment over the reminder of the winter period.

Experiment II. The result of this experiment is interesting because of the unusually low air-temperatures recorded during the exposure period.

The test material consisted of infested wheat with a 13½% moisture content and adults of varying ages. During the exposure period the material was placed in horizontal glass tubes, 27 cms long and with a diameter of 6 cms, roughly three-quarters filled and closed at both ends with 1 mm mesh wire gauze. The air-temperature was read from a minimum/maximum thermometer placed directly beside the tubes. The temperature of the wheat layer can scarcely have differed to that of the air because of its thickness, only approximately 4 cms, and because of its exposed position to the effect of the surrounding air; during a laboratory-experiment carried out later, it was found that infested wheat in the above amount which was taken from room temperature to —20°C in a refrigerator had a temperature of —17° after two hours and —20° after a further two hours.

The exposure time for part of the material covered the 57-day period from October 26th to December 21st, 1955. A study of Fig. 2, in which the minimum and maximum temperatures have been stated, reveals that, during the latter part of the exposure period, the material had been subjected to two periods of very severe cold, closely following and with temperatures of —17° and —21°C respectively. In table form, the following picture is obtained:

Day	Temperature, °C. min.	max.
December 10th	—11	—3
11th	— 11	—5
12th	—15	—5
13th	—11.5	—6
14th	—17	—8
15th	—17	—5
16th	— 6	—3
17th	— 6	—4
18th	— 6	—2
19th	— 21	—2
20th	— 21	—2
21st	21	—8

Of the 414 adults in the said part-samples, 32 i.e. 7.8% had survived the exposure and remained lively, while the developmental stages were totally dead. The result will be dealt with more closely in connection with a retrospect of some earlier data found in literature concerning the effect of severe cold on *S. granarius*.

Through laboratory experiments at constant temperatures, BACK & COTTON, 1924, found that the maximum duration of life for *S. granarius* was 4—5 hours at —17.5°C and 7½ hours at —15°. In

a comparing-experiment at the latter temperature and exposure time, the author, 1938, found a similar 100% mortality. USHATINSKAJA, 1950 a, noted, also in laboratory-experiments at constant temperatures, that all adults of *S. granarius* died within 19 hours at —15°C, and within as short a time as 40 minutes at —20°C. From the present results, however, it must be concluded that the resistance to pronounced falls in temperature of short duration is far greater than that given in the works referred to, if *S. granarius* is subjected to fluctuating outdoor temperatures for a long time during the cold season. This opinion is also supported by the experiments carried out by KIRCHNER, 1940.

In the present experiment, the exposure period for the remaining part of the material was extended to February 2nd, 1956, and thus covered a total of 100 days. All adults were then also dead and nothing else could be expected in view of the extremely severe and continuous cold period which prevailed particularly during the last 4 days of the exposure period; as can be seen in Fig. 2, the minimum temperature on one of these days was —23° and the maximum temperature —19°C.

Although the resistance in *S. granarius* to cold is thus considerable, it is by no means unlimited. Tangible proof

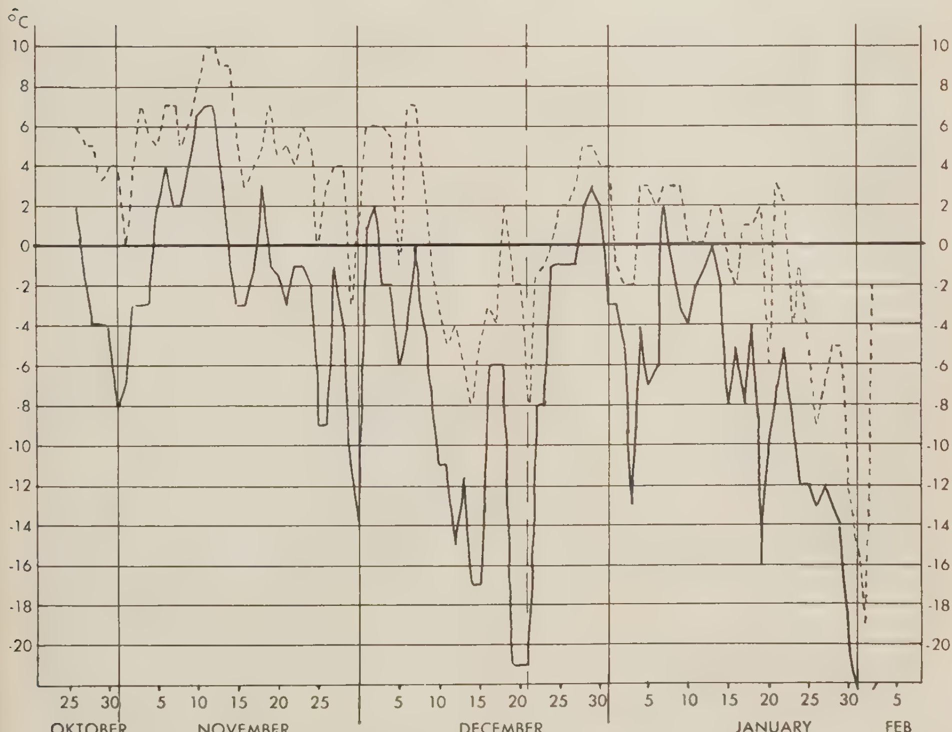

Fig. 2. *Sitophilus granarius.* Minimum and maximum air-temperature during exposure to cold 26.10.—21.12.1955 and 26.10.1955—2.2.1956; experiment II, p. 10.

Fig. 2. *Sitophilus granarius. Minimi- och maximitemperatur under exponering för kyla 26.10.—21.12.1955 och 26.10.1955—2.2.1956; försök II, sid. 10.*

of this is the fact that the species was never capable of overwintering in small stores of infested grain, which, during every year of the period 1954—59, were kept from autumn to spring in the same place as that used in the experiments described. It is also charateristic that *S. granarius* only occurs regularly in the southernmost parts of the country, as far as grain storage premises on farms are concerned. The reason is quite simply that the temperature farther north drops during winter to a level which is lethal to the species, even in the comparatively small grain stores kept on the farms. It will be seen in the next section that the situation is quite different when it comes to more voluminous grain stores.

Overwintering in stored grain

An experiment was carried out in a grain storage depot, 60 kms north of Stockholm, in which 1,000 tons of wheat with a moisture content of 13% were stored. The wheat was stored in bulk in 4—5-metre deep layers.

On December 6th, 1955, a number of small, horizontally placed metal tubes containing infested wheat with a similar moisture content of 13% was inserted in different parts of the stored wheat, some at a depth of 0.2 m and some at 1 metre. The tubes were three-quarters filled and closed at both ends with fine wire gauze. They were kept in the undisturbed wheat until May 13th, 1956, i.e. for a period of just over 5 months.

Readings taken on the permanently installed thermometers showed that the temperature of the wheat at a depth of 1 metre and more was 8 ± 1°C throughout the winter. No readings were taken at the surface of the wheat, but it is obvious that the temperature there was considerably lower. The air-temperatures during the respective winter months at the place in question were lower than normal:

	Mean temperature, 0°C.	
	1955/56	Normal
December	—2.6	—1.3
January	—3.9	—2.5
February	—8.5	—2.6
March	—0.9	—0.4

The experiment gave the following results. All adults and developmental stages of *S. granarius* in the tubes placed at a depth of 0.2 m in the wheat were dead. At a depth of 1 metre, on the other hand, not only had a number of adults survived the winter but also 5% of the developmental stages inside the kernels; the percentage is based on a comparison with the frequency of adults emerged in part-samples of the same infested wheat, which had been separated at the commencement of the overwintering experiment to be kept at room temperature.

The results show that, even quite far north in Sweden, *S. granarius* is capable of overwintering in grain kept undisturbed in deep layers, even in such cases where the infestation is not extensive enough to cause any rise in the temperature of the grain.

With regard to parallel experiments with *Oryzaephilus surinamensis*, see the report on page 24.

Sitophilus oryzae L

During the four-year period 1956/59 infestation by *S. oryzae* occurred to a more or less widespread extent in 8 different long-term stores of grain harvested in Sweden, of which 7 consisted of wheat and 1 of rye. These stores comprised a total of 21,600 tons, but tangible infestation was limited to roughly 10,000 tons. In none of the cases did *S. oryzae* appear alone, but together with *Rhizopertha dominica*, *Oryzaephilus surinamensis* and/or *Laemophloeus* spp. Moreover, *S. granarius* appeared in two of the affected stores. All the stores had, without exception, been laid up for long-term storage in late summer or early autumn at a relatively high temperature, and infestation accompanied by heating was generally found to be in full progress 4—5 months later.

Data illustrating the capacity of *S. oryzae* to reproduce even deep down in the grain and at a temperature in the grain of around 40°C is furnished in connection with the report on *Rhizopertha dominica*, page 15—16 and Table 4, page 15.

It is well known that, compared to *S. granarius*, the resistance to cold in *S. oryzae* is very low, and this is clearly illustrated also by the following reports on parallel experiments with both species of grain weevils.

Overwintering experiments

Some glass vessels, each with approximately 100 grammes of wheat with a moisture content of about 13% and containing adults and developmental stages of both species, were kept in an unheated cellar from November 13th, 1942, to March 24th, 1943. As can be seen in Fig. 3, the air-temperature in the cellar was approximately 4±3°C, thus not falling below 0°C on any occasion. An inspection on January 14th, i.e. after 63 days, revealed total death among *S. oryzae*, while the mortality among *S. granarius* was only between 5 and 10%. At least 25% of the latter

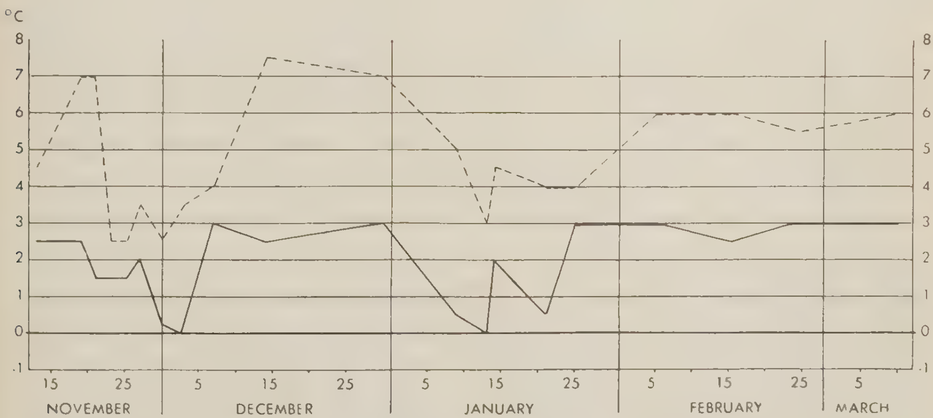

Fig. 3. *Sitophilus oryzae* and *S. granarius*. Minimum and maximum air-temperature in unheated locality 13.11.1942—8.3.1943.

Fig. 3. Sitophilus oryzae och S. granarius. Minimi- och maximitemperatur i ouppvärmd lokal 13.11.1942—8.3.1943.

species were still living on March 24th when the experiment was concluded.

Exposure to outdoor temperature in winter

The experiment was performed in the same place as that used for the previously described experiments with *S. granarius.* Wheat containing developmental stages of *S. oryzae* and adults of both species was transferred there on December 1st, 1959, after a preparatory reduction in temperature to about 10°C. The temperature was measured daily and the readings are given in Fig. 4. The exposure period was from December 1st—21st, i.e. 21 days. At the beginning of this period the moisture content of the wheat was 13.5%, but it rose gradually to 15.5%.

It can be seen from the figure that the temperature of the wheat during the 8-day part-period from December 3rd—10th fluctuated between —5 and —1.5°, its mean temperature being roughly —3.5°. Samples taken from the wheat at the end of the said part-period showed that 5% of the adults of *S. oryzae* and approximately 65% of *S. granarius* had survived, as had also about 2% of the developmental stages of *S. oryzae.* At the end of the exposure period on December 21st, total death had occurred in *S. oryzae,* including developmental stages, while mortality in the case of *S. granarius* was approx. 60%.

Cotton, 1956, page 79, gives 8 days as maximum duration of life in *S. oryzae* at a temperature of 25—30°F. (= —4 to —1°C). In the experiment just described it can be seen that higher values were obtained for the resistance of the species. Under all conditions, however, the resistance is very low.

Ushatinskaja, 1950 a, found in laboratory experiments that the developmental stages, especially the eggs, in *S. oryzae* displayed a considerably greater resistance to cold than the adults; as is well known, the situation is quite the opposite in the case of *S. granarius.* At a temperature of between —4 and —6°C, adults of *S. oryzae* thus lived for a maximum of 4 days and eggs for 12 days; at —8.5 to —10° adults lived 15 hours and eggs 90 hours. Wheat with a 15—18% moisture content had been used for rearing.

The regular import every year of grain from warmer countries provides *S. oryzae* and certain other species of pests with low resistance to cold with a better chance of even infesting grain harvested in Sweden. In places where grain is stored under conditions which prevent it from becoming sufficiently cold during winter, the pests also have the possibility of surviving from one year to the other.

Fig. 4. *Sitophilus oryzae* and *S. granarius.* Temperature of infested wheat during exposure to cold 1.12.—21.12.1959.

Fig. 4. *Sitophilus oryzae* och *S. granarius. Temperatur hos angripet vete under exponering för kyla 1.12.—21.12.1959.*

Rhizopertha dominica F

This species appeared in 5 of the large, infested grain stores mentioned in the report on *S. oryzae*. In several of these cases, *Rh. dominica* displayed a marked augmentation. With regard to extent of damage, it was the dominant species.

Occurrence, together with other species of pests, at great depths in bulk grain

In connection with the sampling of affected grain stores, it was observed that *Rh. dominica*, as well as certain other species, reproduces without difficulty in bulk grain even at considerable depths. This can be illustrated by some results of sampling carried out on February 17th, 1960 in a store of Swedish wheat harvested in 1958, which had been laid up for long-term storage in July 1959 and which at the end of September/beginning of October had begun to display a marked rise in temperature as a result of infestation. The figures below refer to the frequency per kilogram of wheat of adults already present during sampling, and of younger adults emerged after the wheat samples had been kept for 1 month at 28°C in a thermostat.

4.0 metres:	*Rhizopertha dominica*	5+19
	Laemophloeus ferrug.	0+14

Table 4. Rhizopertha dominica, Sitophilus oryzae and Laemophloeus ferrugineus. Adults and developmental stages pr kg heating wheat.
L = Living, D = Dead, E = Young adults emerged 4 weeks later.

Tabell 4. Rhizopertha dominica, Sitophilus oryzae och Laemophloeus ferrugineus. Skalbaggar och utvecklingsstadier per kg vete i en värmehärd.
L = levande, D = döda, E = nykläckta skalbaggar 4 veckor senare.

Group of samples *Grupp av prov*	Depth in metres *Djup i meter*	Temperature 4.12. °C.	Rh. dominica adults *skalbaggar* 4.12. L	Rh. dominica adults *skalbaggar* 4.12. D	Rh. dominica E	S. oryzae adults *skalbaggar* 4.12. L	S. oryzae adults *skalbaggar* 4.12. D	S. oryzae E	L. ferrugineus adults *skalbaggar* 4.12. L	L. ferrugineus adults *skalbaggar* 4.12. D	L. ferrugineus E
I	0.5	10	0	0	0	0	0	0	0	0	0
	1	32	0	0	0	0	0	4	0	0	0
	2	40	0	8	183	0	16	0	0	0	0
	3	39[1]	45	40	165	15	0	360	20	15	65
II	0.5	11	0	0	0	0	0	0	0	0	0
	1	19	0	0	0	0	0	0	0	0	0
	2	37	20	24	992	0	12	0	0	0	20
	3	38[2]	19	4	277	0	4	177	0	4	23
III	0.5	20	0	1	0	0	0	0	0	0	0
	1	36	40	10	53	4	2	88	0	0	0
	2	39	0	5	332	0	18	0	0	0	18
	3	39[3]	13	17	204	0	8	0	0	0	5

[1] Temperature 24.11.=36°, 1.12.=43°
[2] » 1.12.=43°
[3] » 1.12.=36°

4.1 metres:	*Rhizopertha dominica*	22+67
	Sitophilus oryzae	22+10
	Laemophloeus ferrug.	0+55
4.7 metres:	*Rhizopertha dominica*	32+ 5

The moisture content of the wheat in the above samples was very low: only 9.5% at a depth of 4.1 metres. As mentioned previously, a decrease in the moisture content of the grain at deeply located heat- and infestation-points proved to be a regularly occurring phenomenon which was evidently due to the moisture being carried away with the warm air and then, in certain cases, condensing on the surface. *Rh. dominica* displayed a marked ability to survive in grain thus dried out.

Tolerance to high temperatures in infested grain

Table 4 contains the results of sampling carried out on December 4th, 1959 at three different places in a large heat spot found in a 2,200-ton lot of Swedish wheat, 4 metres deep and laid up in July of the same year. Heating was observed in the middle of November within an area of the store comprising just over 50% of its total volume. As can be seen, living adults and developmental stages appeared in abundance, mostly of *Rh. dominica* but also of *S. oryzae* and *Laemophloeus ferrugineus,* in a part of the wheat store where the temperature at the time was 39—40°, having reached 43° some time before. The moisture content of the wheat samples was 11.5%.

Weight losses in grain as a result of feeding

As a grain store was being attacked by *Rh. dominica* an estimation was made as to the direct weight loss resulting from the pests feeding on the kernels. The store contained 1,000 tons of Swedish wheat from the harvest of 1957. After drying to a 13% moisture content, the wheat was laid up during August—October in a granary situated 60 kilometres north of Stockholm. The storage depth was 8 metres. It should also be mentioned that, at storage, 1 kilogram of a pyrenone powder had been added to each ton of wheat.

At the beginning of January, 1958, i.e. 2—3 months after the store had been laid up, it was noticed that the temperature at a depth of 2—3 metres had begun to rise. However, this was neutralized by blowing during the following winter months, and the temperature in the middle of April varied between 6 and 12° in different parts of the store. The reason for heating was the presence of a moderate number of *Rh. dominica* as well as isolated cases of *S. oryzae* and *Laemophloeus minutus*.

In July, however, an abnormal rise in temperature was again observed higher than the previous one and covering the wheat layer at a depth of between 4 and 7 metres. At the beginning of November, when the temperature at several points in the warm zone was 40°, a number of wheat samples were taken from the zone. For each kilogram of wheat, the samples contained an average of 5 living adults of *Rh. dominica,* and further 73 emerged within about 6 weeks.

A representatively average sample of wheat was subjected to a thorough investigation as to the damage caused by feeding on the outside of the kernels. The following results were obtained:

All kernels 100 grammes, number 2870, average weight per kernel 34.8 mgm
of which undamaged 88 grammes, number 2436, average weight per kernel 36.1 mgm
of which damaged 12 grammes, number 434, average weight per kernel 27.7 mgm.

Average weight loss per damaged kernel = 8.4 mgm.

Calculated weight of 2870 undamaged kernels = 103.61 grammes.

Weight loss as a result of feeding = 3.5%.

As the infested part of the store in question comprised between 450 and 500 cu.m., the direct weight loss resulting from feeding on the kernels can be estimated at a round figure of 13 tons at the time of the investigation, thus corresponding to 1.3% of the entire wheat store.

The resistance in *Rh. dominica* to cold is generally given in literature as being negligible; cf. DENDY & ELKINGTON, 1920, FREEMAN & TURTLE, 1947, SOLOMON & ADAMSON, 1955. The last-mentioned, however, report a case where the species survived the mild winters of 1948/49 and 1949/50 in stacks of bagged (not heating) barley in unheated huts of corrugated iron in England. Two of the author's own experiments will be described in the following.

Resistance to cold in laboratory experiments

Table 5 contains the results of parallel experiments with *Rh. dominica* and *S. granarius*. Approximately 200 adults of each species were kept in common glass vessels containing 2 cms of wheat with a moisture content of 13% and with thermometers thrust down into the wheat. Before being exposed for the times given in the table, the insects were subjected to a preparatory reduction in temperature from room temperature to 16°C during a period of 48 hours. As the table shows, the exposure time comprised a first period at about 13°, followed immediately by the cold period proper. The effect of the treatment was not determined until the material had first been kept at room temperature for 8—10 days after finished exposure.

As can be seen from the table, the resistance in *Rh. dominica* was low compared to that in *S. granarius*. Nevertheless, 27.8% of the adults survived a 10-day exposure at —1.5°, which means a not insignificantly greater degree of resistance than that given by DENDY & ELKINGTON, namely that no adults survived 11 days at 0.6 to 2.2°C. It is reasonable to assume that the divergence of the results could have something to do with the long, preparatory exposure at a moderately low but not lethal temperature employed in the experiments described here.

Exposure to outdoor temperature in winter

Approximately 25 kgs of infested wheat with a 12% moisture content were kept in a 20-cm thick layer in a container placed in a hut during the period November 5th 1957—January 10th 1958. The temperature of the wheat was measured daily and the readings obtained are given in Fig. 5.

The first sample was taken from the wheat on December 12th, i.e. after 37 days' exposure to outdoor temperatures. Fig. 5 shows that after the first three days of the part-period the temperature in the wheat never exceeded 4°; its mean temperature for the following 34 days

Table 5. Rhizopertha dominica. Resistance to cold, compared with S. granarius, in laboratory experiments.

Tabell 5. Rhizopertha dominica. Motståndskraft mot kyla i laboratorieförsök jämsides med S. granarius.

Part-period I *Delperiod I*		Part-period II *Delperiod II*		% adults dead *% skalbaggar döda*	
Temperature *Temperatur* °C.	days *dagar*	Temperature *Temperatur* °C.	days *dagar*	Rhizoph. dominica	S. granarius
13 ± 0.5	7	5 ± 0.5	18	78.7	7.5
13 ± 0.5	25	— 1.7 ± 0.3	5	40	1.2
13 ± 0.5	35	— 1.5 ± 0.5	10	72.2	1
13 ± 0.5	7	— 1.2 + 0.5	18	100	18.3

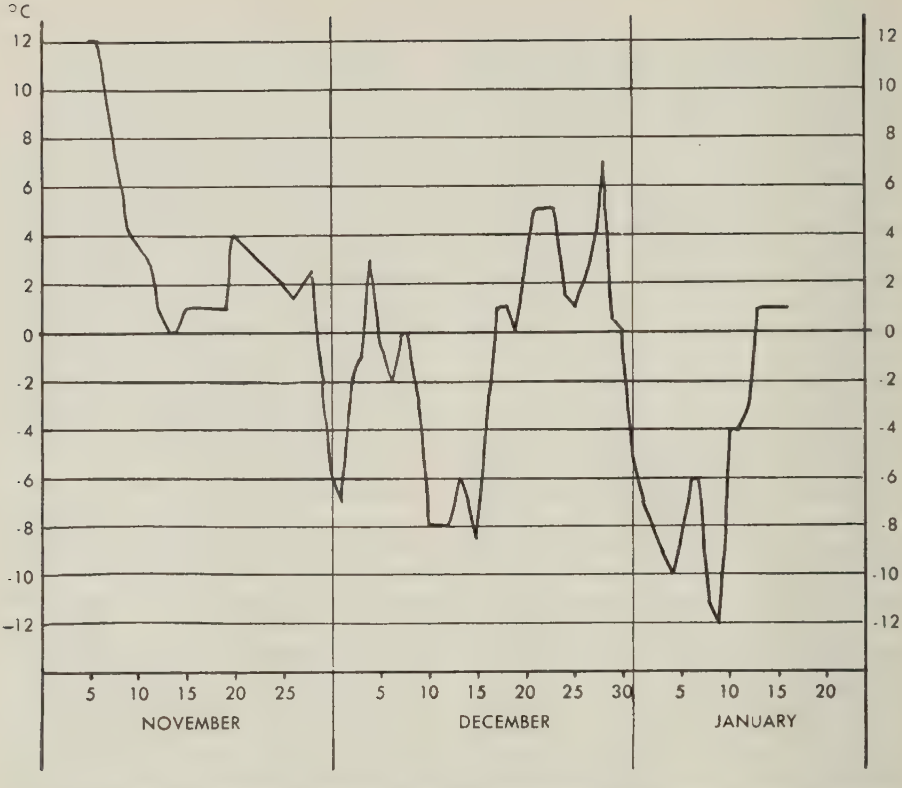

Fig. 5. *Rhizopertha dominica, Laemophloeus ferrugineus* and some other species. Temperature of infested wheat during exposure to cold 5.11.1957—10.1.1958.

Fig. 5. *Rhizopertha dominica, Laemophloeus ferrugineus m. fl. arter. Temperatur hos angripet vete under exponering för kyla 5.11.1957—10.1.1958.*

was approximately 0°C. The figure also shows that the temperature of the wheat at the turn of the month Nov./Dec. remained at a constant —6° to —7° for 48 hours, and at —8° for three days at the end of the part-period. 4.5% of the adults present in the sample were living after having been kept at room temperature for 10 days and appeared fully vital.

It was thus made evident that the species is capable of surviving at least short periods of cold. However, in the following samples taken on January 2nd and 10th, both adults and developmental stages were all dead.

Laemophloeus ferrugineus Steph

L. ferrugineus is the most common species of all pests to be found in grain stored over long periods in Sweden. During the period 1954/59, large-scale infestation by insects occurred in 15 different long-term stores of grain. *L. ferrugineus* was found in 12 of these which comprised a total of 29,500 tons, 11,000 tons of which displayed a more or less high degree of heating as a result of infestation. All 12 stores consisted of wheat harvested in Sweden. In one of the infested stores, *L. ferrugineus* was the only species of pest occurring; in the remaining cases, other species were also found. *L. minutus* has been met with sporadically, but mass reproduction of this species has occurred only in one isolated case.

Breeding experiments at sub-optimal temperatures

A mixture of whole and split wheat-kernels with a moisture content of about 14% was used to breed the insects. An amount of 30 grammes in 1-cm thick layers in glass vessels was given to each of 50 adults. The kernels and insects were first kept apart for 3 days at the respective experimental temperatures.

The number of adults of a new generation, reckoned per 100 adults originally present, were as follows after approximately 100 days and at the various breeding temperatures; the figures represent the mean of two parallel experiments:

15.5 $\pm$ 1°C	0
16 $\pm$ 1	2
17 $\pm$ 1	5
19 $\pm$ 1	24

As can be seen, a certain reproduction, although insignificant, occurred while the temperature was only fluctuating between 15 and 17°. It would seem justifiable to conclude that an initial temperature as given above in stored grain can suffice to enable a gradual mass reproduction of *L. ferrugineus* to take place. As is well known, when infested grain is stored in deep layers, there is an accumulation of heat developed in connection with the insects' and larvae's metabolism.

Resistance in adults to cold in laboratory experiments

During the exposure periods the adults were confined in horizontally placed glass tubes, 10 cms long and 1.5 cms in diameter, and closed at both ends with fine wire gauze. Before the actual cold treatment, they were subjected to a preparatory reduction in temperature for 7 days at about 6°C. In a similar manner they were brought gradually back to room temperature after finished exposure. After a further 7 days at room temperature the effect of the treatment was determined.

Table 6 contains the results of the experiment in which the percentages represent the mean value of 4 repeated procedures on 50 adults. The resistance was somewhat lower than that given for *S. granarius* in Table 2, page 7. The next section will show that the situation is different when developmental stages are included in the experiment.

Exposure to outdoor temperature in winter

In the experiment with *Rh. dominica* (exposure of infested wheat of 12% moisture content) described on page 17, adults and developmental stages of *L. ferrugineus, S. granarius, S. oryzae* and *O. surinamensis* were also included.

The duration of exposure covered the 67-day period from November 5th 1957 —January 10th 1958. As shown by Fig.

5 the temperature of the wheat during this time displayed marked fluctuations. In addition, three different part-periods of heavy temperature falls can be distinguished, during which the following bottom values were reached:

Nov. 30th—Dec. 1st, 2 days, min. —7, max. —6°C.

Dec. 10th—15th, 6 days, min. —8.5, max. —6

Jan. 1st—9th, 9 days, min. —12, max. —6.

All adults of *L. ferrugineus* were dead but not so the developmental stages. After the wheat had been kept for 6 weeks at 26—27° following finished exposure, it was found that an average of 3 adults per kilogram of wheat had emerged, and this frequency was approximately as high as that found after an earlier sampling taken at the turn of the month December/January. All other species in the experiment, including *S. granarius*, were dead.

As was the case with *S. granarius* (see page 12), neither did *L. ferrugineus* survive the winter six months in small amounts of infested grain during overwintering experiments which were carried out in the experimental place near Stockholm every year during the period 1954/59. As regards the southern parts of Sweden, experience shows that, as is the case with *S. granarius*, the species often overwinters there in unheated granaries where no large quantities of grain are stored.

Table 6. Laemophloeus ferrugineus. Resistance in adults to cold in laboratory experiments.

Tabell 6. Laemophloeus ferrugineus. Motståndskraft hos fullbildade skalbaggar mot kyla i laboratorieförsök.

Temperature *Temperatur* °C.	Duration of exposure, days *Exponeringstid, dagar*	% dead *% döda*
0 ±1	45	97.4
	60	100
—2 ±0.5	25	73
—4 ±1.5	20	74.4
	26	89.8
—5 ±1	28	99.4
	30	100
—5.5 ±1.5	15	61
	20	100

Oryzaephilus surinamensis L

During the period 1956/59, this species appeared as a pest in 6 different long-term stores of grain harvested in Sweden, including both wheat and rye. The heating caused by infestation affected a total of approximately 4,900 tons of the stores in question. Infestation to a more or less heavy degree has occasionally occurred also in stores of malt and barley.

Acting as a primary pest in stored grain

In two of the above-mentioned stores of bread grain, in which infestation and accompanying heating occurred, the only pest present was *O. surinamensis*. Howe, 1956 p. 354, has for certain reasons questioned the ability of the species to cause heating and assumes that the species benefits from heating rather than causes it. Freeman, 1951, p. 8, on the other hand, maintains that the opposite is true and quotes examples of *O. surinamensis* having caused heating. Experience acquired in Sweden points unmistakably to the occurrence and activity of this species as the direct cause of heating in stored grain. The following report of an actual case may serve as an example.

In the autumn of 1953, 1,400 tons of Swedish wheat from the harvest of the same year were laid in store in a barn in central Sweden which had been rebuilt and equipped for storing grain. The building was of sound and practical construction in all respects and in a good state of repair, and it had already been used for several years as a grain warehouse without any storage damage whatsoever having been caused. The wheat was delivered cleaned and dried to a moisture content of 13%. In the middle of November of the same year, a considerable rise in temperature of up to about 35° was observed in the 4—5-metre deep layer of wheat and localised to two different sources. The wheat was sampled and a fairly severe degree of infestation by *O. surinamensis* was found to be in progress, with a frequency of 50 to 80 living adults and larvae per kg wheat at the time of sampling. No other species of insects occurred anywhere in the store. The waste content in the form of dust and powder caused by gnawing was ½ weight per cent in the grain samples taken from the heating sources, the moisture content was about 13% while the temperature of the wheat outside the sources varied between 16 and 19°C at the different points. The circumstances throughout were such that no conceivable cause of heating in the wheat store could be found other than the presence of *O. surinamensis*.

In connection with this case, it was also remarkable to find that a relatively severe infestation by *O. surinamensis* could already be in progress only a few months after the grain had been harvested. In all probability, the wheat in question had been affected as a result of residual infestation in the silos contained in the warehouse where the wheat had been cleaned and dried before being delivered. Unfortunately, data concerning the temperature of the wheat before and immediately after delivery is not available, but judging by the temperatures in November in the non-infested parts of the store and also by the air-temperature in the district during that particular autumn, it could scarcely have exceeded 20". The air-temperatures were as follows:

September,	mean 11.4°C.,	min. 3°C.,	max. 20.2°C.
October,	9.4	1	18
November,	3.5	—5.2	10.4

The ability of *O. surinamensis* to live as a primary pest in wheat has also been observed in several laboratory experiments, one of which will be described in brief.

During ocular inspection of each individual kernel, 50 grammes of wheat kernels which appeared to be completely undamaged and with a moisture content of 14% were selected. After the addition of 50 adults of *O. surinamensis,* the kernels were kept in a thermostat at 23°C. The following observations were then made:

After 14 days. Numerous adults feeding on and partly inside the kernels.

After 25 days. Numerous larvae among the kernels.

After 195 days. 133 living adults and a great (uncounted) number of pupae and larvae.

Occurrence at great depths in bulk grain

In connection with the report on *Rh. dominica,* it was shown, on page 15, that certain species of pests are capable of surviving at great depths in bulk grain. The following case will serve to show that this is also characteristic of *O. surinamensis.* In a store of rye comprising 3,200 tons, which had been laid up in late summer 1958 and then remained undisturbed, a high degree of heating in connection with infestation by *O. surinamensis* was observed at the turn of the month January/February 1959. The source of heating was located in the centre of the store, and sampling carried out on March 9th from rye at various depths there gave the following number of insects and developmental stages, counted per kg rye.

Depth in metres	No. of adults March 9th living	dead	No. of adults and larvae emerged 4 weeks later
Surface	236	144	86
0.5	202	25	122
1	59	24	10
1.5	122	17	19
4	43	486	14
5	685	100	343

Breeding experiments at sub-optimal temperatures

The food used for breeding consisted partly of whole wheat kernels and partly of a mixture of whole and coarse ground kernels of wheat and oats. The method was otherwise the same as that employed in experiments on *L. ferrugineus* described on page 19; the moisture content of the food, however, was somewhat higher, viz. 14.5 to 15%.

The results are given in Table 7. As is shown, no larvae were produced at a temperature fluctuating between 15.5 and 17.5°C. The minimum temperature for the development of larvae and pupae lay between 17 and 18°, while a somewhat higher temperature, 18—18.5°, was needed for the production of living adults. In breeding experiments at 17.5°, Howe, 1956, found that, after reaching the pupal stage, *O. surinamensis* failed to produce any living adults. The results of experiment III shown in the table tally well with Howe's finding in that, of the 70 pupae developed at 17.5 ± 0.5°, only 2 living adults were produced and that did not occur until the temperature had risen to 18 ± 0.5°C.

The figures given in the table also show that the duration of life of adults at the temperatures in question was quite long. In experiment II, 25% were still living after 19 months at a temperature of 17°. While no reproduction had taken place, there had been a considerable amount of feeding; cf. footnote in the table. Experiment I shows that a high percentage of adults were still living after 6½ months at a temperature of 12.5 to 13.5°, and that the increase in temperature which later occurred was soon reflected in the commencement of reproduction.

Resistance in adults to cold in laboratory experiments

The same method was employed as that used for the experiments with *L.*

Table 7. Oryzaephilus surinamensis. Breeding experiments at sub-optimal temperatures.

Tabell 7. Oryzaephilus surinamensis. Uppfödningsförsök vid underoptimala temperaturer.

Experiment No.	Part-periods in chronological order / *Delperioder i kronologisk ordning*		Surviving adults / *Överlevande skalbaggar* %	Offspring, per 100 parent-adults, at the end of part-periods / *Avkomma per 100 moderdjur vid slutet av delperioderna*			
	days / *dagar*	temperature, °C. / *temperatur*		larvae / *larver*	pupae / *puppor*	adults / *skalbaggar*	total / *totalt*
I	193	13 ± 0.5	68.5	0	0	0	0
	83	18	56	10	0	0	10
	276						
II*	136[1]	15.7 ± 0.7	87	0	0	0	0
	98	16.5 ± 1	70	0	0	0	0
	36	17.7 ± 0.3		0	0	0	0
	27[2]	16.5 ± 1	56	0	0	0	0
	223	16 ± 1	25	0	0	0	0
	520						
III	104	17 ± 0.5	88	0	0	0	0
	59	17.5 ± 0.5	80	36	0	0	36
	64	17.5 ± 0.5	72	150	70	0	220
	49	18 ± 0.5	54	362	4	2	368
	276						
IV	104	22	70	87	80	65	232

* Experiment II. Excavated kernels per 100 beetles: 28 and 56, respectively, after a total of [1]136 and [2]297 days.
Experiment II. Urätna kärnor per 100 skalbaggar: 28 resp. 56 efter totalt [1]136 och [2]297 dagar.

ferrugineus described on page 19. The following results were obtained.

Temperature °C.	Duration of exposure days	Dead %
—2	21	94.7
—2	25	100
—5	20	100
—5.5 ± 1.5	10	97
—5.5 ± 1.5	15	100

It is evident that *O. surinamensis* possesses far less resistance than *S. granarius* and *L. ferrugineus;* cf. Tables 2 and 6.

Exposure to outdoor temperature in winter

The results of exposing wheat with a 12% moisture content and infested by different species of pests have already been given in the section on *Rh. dominica,* page 17, and *L. ferrugineus,* page 19; the temperatures in the wheat during exposure, which covered the period Nov. 5th 1957—Jan. 10th 1958, are given in Fig. 5. As previously mentioned, developmental stages of *L. ferrugineus* survived the entire exposure period. On the other hand, as early as Dec. 12th, both adults and developmental stages of *O. surinamensis* were dead; at the same time, mortality in adults of *Rh. dominica* was approximately 95 %, in *S. granarius* 26%, and in *S. oryzae* 100%.

Overwintering in stored grain

The overwintering capacity of *O. surinamensis* was investigated in parallel with that of *S. granarius* in the experiment described on page 12. About 150 adults of the former species were kept in a number of metal tubes at depths of 0.2 and 1 metre in the wheat store.

When the experiment was concluded in May 1956, it was found that all beetles at a depth of 0.2 m were dead. However, at a depth of 1 metre (temperature during the entire winter $8 \pm 1°$), isolated specimens were found living in each of the three tubes placed there. The mean percentage of surviving, lively adults was 1½.

Despite its comparatively limited resistance to cold, *O. surinamensis* is thus capable of overwintering in large grain stores as far north as central Sweden, even if there is no heating.

Trogoderma granarium Everts

This species has only appeared occasionally as a pest in Sweden. In the beginning of the 1940's, quite severe infestation occurred in a large quantity of imported barley, and there was also a case of larvae occurring in profusion in a quantity of sugar stored in sacks, as a result of residual infestation in the holds of the ship in which the sugar was transported. A severe case of infestation occurred during the winter 1955/56 in connection with heating in a store of groundnut cakes imported from Nigeria.

A number of experiments were carried out during the 1940's to investigate the possibilities of survival and continued existence of the species in Sweden, and these will now be described.

Breeding experiments at various temperatures

The basic material consisted of larvae of varying ages placed in petri-dishes containing a layer of wheat kernels about 2 cms thick. The number of larvae in each dish was approximately 100. The relative atmospheric humidity in the breeding container was 65 ± 5%. The breeding experiments were started on September 9th, 1942 and continued until November 10th, 1944, i.e. for a period of 2 years and 2 months.

The temperatures in the results of the experiments A, B and C given below refer to the respective part-periods of the *two* years.

A). October—May 6 ± 2°C.
June—September 9 ± 3°C.
After 17 months, roughly 50% of larvae dead, no feeding.
After 26 months 100% of larvae dead, no feeding.

B). October—May, 10.5 ± 1.5°C.
June—September 15 ± 2°C.
After 17 months, all larvae living, no feeding.
After 26 months, 89% of larvae dead, negligible feeding, affecting only split kernels.

C). November—April 16 ± 1°C.
May—October 19 ± 2°C.
After 10½ months, isolated pupae, negligible feeding.
After 17 months, isolated adults (dead), negligible feeding.
After 26 months, adults (all dead) = 22% of the number of larvae supplied. No pupae, no new generation of larvae. Of the remaining larvae 35% living, 65% dead.

D). Temperature constant at 25°C.
After 1½ months, isolated adults, extensive feeding.
After 10½ months, abundance of living and dead adults, copious new generation of larvae.

These results reveal that the minimum temperature for reproduction is between 20 and 25°C. (cf. HADAWAY, 1956) and for feeding in larvae about 15°. Experiment A showed that non-feeding larvae lived in great numbers at the end of 17 months but were dead after 26 months. When the temperature rose somewhat higher periodically, as in experiment B, so that a certain degree of feeding — although negligible — but no production of pupae occurred, approximately 10% of the larvae were still living after 26 months.

Since the species requires such a high temperature for reproduction, it is scarcely probable that it could become stationary in a country with the climatic conditions of Sweden. Conceivable exceptions are heated plants such as those used in malting, but no such case of infestation has yet occurred. The risks of infestation are generally small as malting plants in Sweden use nothing but domestic corn except in very rare cases.

Minimum temperature for activity in larvae

A number of groups, each containing 3 larvae of varying ages, were placed on filter papers in open glass vessels and put into refrigerators equipped with a window to enable observations to be

made from outside. Fluctuations in temperature amounted to only ± 0.1°C. Observations were made daily during the course of several weeks and the position of the larvae on the filter papers was recorded on sketches.

The lowest temperature at which any measurable change in position occurred was found to be 6.5°C.

Resistance in larvae to cold in laboratory experiments

For these experiments, a number of refrigerating chambers equipped with fans for air circulation was used. Temperature fluctuations in each chamber kept to within ± 0.5°C. Each part-experiment comprised between 400 and 500 larvae of varying age. These were placed in horizontally positioned glass tubes, 10 cm long and closed at both ends with wire gauze. Before and after exposure, the larvae were subjected to a preparatory decrease and increase in temperature respectively as per the following:

Experiment temperature —2 and —5.5°
  Before exposure 10° for 4 days, 4° for 2 days
  After exposure 4° for 2 days, 10° for 4 days
Experiment temperature —10 and —19°:
  Before exposure 4° for 2 days, —5° for 2 days
  After exposure —5° for 2 days, 4° for 2 days.

Table 8. Trogoderma granarium. Resistance in larvae to cold in laboratory experiments.

Tabell 8. Trogoderma granarium. Motståndskraft hos larver mot kyla i laboratorieförsök.

Temperature *Temperatur* °C.	Duration of exposure, days *Exponeringstid, dagar*	Percent dead 10 and 30 days after finished exposure *Procent döda 10 och 30 dagar efter avslutad exponering*		Notes *Anm.*
		10 days *10 dagar*	30 days *30 dagar*	
—2	120	1.0	1.3	Surviving larvae lively 50 days after finished exposure. *De överlevande larverna vitala 50 dagar efter avslutad exponering.*
	180		44.7	43% of surviving larvae lively. *43 % av överlevande larver vitala.*
—5.5	90	16.1	23	77% of surviving larvae lively. *77 % av överlevande larver vitala.*
—10	30	11.2	97.5	All surviving larvae lively. *Alla överlevande larver vitala.*
—19	5		67	96.4% dead 4 months after finished exposure; of surviving larvae 50% lively. *96,4 % döda 4 månader efter avslutad exponering; av de överlevande larverna 50 % vitala.*
	10		99.8	All surviving larvae lively. *Alla överlevande larver vitala.*
	15	100	100	

At the end of the exposure period, the larvae were kept at 22°. The effect of the cold treatment was investigated first after 10 and then after about 30 days at this temperature. In some cases, the investigation continued for an even longer time.

The results, which are compiled in Table 8, show that the larvae of *Tr. granarium* possess extraordinarily high resistance to cold. A certain percentage of them were able to survive exposure at —2°C for 180 days, at —5.5° for 90 days, at —10° for 30 days and at —19° for 10 days.

Overwintering in unheated buildings at outdoor temperature

During the entire period Dec. 8th 1942—May 19th 1944, i.e. two winters and an intervening summer period, a collection of larvae of varying ages were kept in the experimental building near Stockholm which has been mentioned before; cf. *S. granarius*, page 8. The larvae numbered 996 and were kept together with a 5-cm thick layer of wheat with an initital moisture content of approximately 13% in a large glass vessel covered with fine wire gauze. A minimum/maximum thermometer was placed close by.

Because of the small quantity of grain, the larvae were of course constantly exposed to the fluctuations in the temperature of the surrounding air.

During the two winters there were several periods of severe cold as can be seen in Table 9, which contains extracts from the temperature log kept during the entire exposure period.

When the material was investigated on May 19th, 1944, it was observed that approximately 50 larvae, i.e. 5% of the total number, had survived and appeared lively. The wheat was dry and contained a moderate amount of gnawing powder and exuvia. One noteworthy observation was that no pupae or adults had developed; cf. Solomon & Adamson, 1955, pp. 343/4.

The results of the experiments lead to the conclusion that, at the larval stage, *Tr. granarium* has sufficient resistance to cold to enable the species to overwinter, even in an exposed state, in unheated buildings, at least as far north as central Sweden. The factor which, despite this, prevents the species from becoming stationary as a storage pest is, as mentioned earlier, the high minimum temperature required for reproduction.

Table 9. Trogoderma granarium. Periods of severe frost during exposure-period 8.12.1942—19.5.1944, = 17 months

Tabell 9. Trogoderma granarium. Perioder av stark kyla under exponeringstiden 8.12. 1942—19.5.1944, = 17 månader.

Day *Dag*		min. °C.	max. °C.
1943, January	9.	— 12	— 3
	10.	— 22.2	— 12
	11.	— 22	— 15
	12.	— 16	— 11
	13.	— 9	— 3
	—		
	21.	— 10	1
	22.	— 11	0
	23.	— 6	0
	24.	— 6	— 4
	25.	— 21	— 5
	26.	— 5.5	— 2
	—		
1944, January	9.	— 6	— 1
	10.	— 13	— 2
	11.	— 16	— 11
	12.	— 14	— 7.5
	13.	— 18	— 6
	14.	— 19	0.5
	15.	— 8	1.5
	—.		
February	20.	— 8	— 3
	21.	— 8	— 1.5
	22.	— 7	0
	—		
	27.	— 12.5	— 1
	28.	— 15.5	— 2
	29.	— 15	0
	—.		
March	30.	— 14	— 2.5
	31.	— 16	— 2
April	1.	— 14	1
	2.	— 11	1

Ptinus tectus Boield

Imported oil cakes very often display slight or severe infestation by *Pt. tectus*. When these products are stored over long periods, it has happened on several occasions that the species has mass reproduced and caused considerable damage. In some cases, shipments not originally infested have been attacked and damaged as a result of cross-infestations or residual infestations.

In southern Sweden at least, observations have revealed that *Pt. tectus* overwinters in stores of infested products laid up in cold premises. The experiments which will now be described also show that the resistance to cold exhibited by the species is quite high.

Resistance to cold in laboratory experiments

Free adults and larvae removed from their cocoons were selected for this experiment from cultures on crushed groundnut cakes at room temperature. The refrigerating chambers and other experimental devices used were the same as those used in the experiments with *Tr. granarium* described on page 26. A preparatory decrease in temperature covered 5 days at 12°C and 2 days at 4°; the return to room temperature after finished exposure to cold was via 4° for 1 day.

A). *Adults.*

The effect of exposure to cold was investigated after the beetles had been kept at room temperature for 14 days.

Temperature °C	Duration of exposure days	Dead %
0	90	77
—1	61	70
—5	30	70

B). *Larvae.*

In one experiment, large larvae were exposed to a temperature of 0° for 60 days and then transferred immediately to a temperature of —5° for a period of 45 days. The effect of these exposures was as follows:

1st part-period, temp. 0°, 60 days: 0 % dead

2nd part-period, temp. —5°, 45 days: approx. 50 % dead.

A subsequent check was kept on the surviving larvae for a period of 2 months after the conclusion of treatment. No later mortality occurred and all larvae spun themselves in cocoons. 30 % developed to adults after 2 months.

It seemed evident that the long exposure of the larvae to 0° preceding the change to the lower temperature brought about an increase in resistance. This is supported by the fact that after transferring some of the larvae at the end of the short-lasting, preparatory decrease in temperature at 12° and 4° direct to —5°, these larvae were all dead after exposure for 50 days.

The above-mentioned values in respect of the resistance to cold in larvae of *Pt. tectus* are considerably higher than those obtained in the experiments performed by Howe & Burges, 1953, according to which large larvae died after 13 days' exposure to approximately —3°C.

Among other results obtained in experiments with free, large larvae, it may be mentioned that exposure for 90 days at —2°C resulted in 100% mortality.

Exposure to outdoor temperature in winter

The resistance in *Pt. tectus* was tested in parallel experiments with *S. granarius* in the exposure of infested wheat described on page 8 and in Fig. 1. A cloth bag containing 600 grammes of coarseground groundnut cakes together

with approximately 1,000 adults of *Pt. tectus* was embedded in the wheat-filled container.

The duration of exposure covered the period Oct. 8th 1958—Feb. 4th 1959. On investigation 14 days after the end of the period, about 10% of the adults of *Pt. tectus* were still living. The majority of the survivors appeared lively, but no control of ensuing death, reproduction etc. was carried out. Since mortality in adults of *S. granarius* in the same experiment was 95%, the result indicates that the resistance in *Pt. tectus* is at least as high as in the first-mentioned species.

Ephestia kühniella Zell

This species is spread over almost the entire country, mainly as a pest in flour and grain mills. From the point of view of combating it, the knowledge of its reaction to cold is naturally of great practical significance, particularly in view of the widely varying climatic conditions in different parts of the country.

Minimum temperature for reproduction

A series of experiments was performed at temperatures varying between 7 and 13°C. Adults newly-hatched from cultures kept at approximately 18° were isolated for two days at the respective test temperature, after which males and females were put together in pairs.

The lowest temperature during these experiments at which copula and egg-laying occurred was 8°. No eggs were fully hatched however, until the temperature was raised to a little over 10°.

Incubation period of eggs at various temperatures

In each individual experiment, 100—300 eggs from many different females were used.

Temperature °C	Shortest incubation period days
20 ±1	8
16.5±0.5	13
14 ±0.5	18 (90% hatched within 19 days)
11 ±2	41 (mortality 92.3%)

Resistance in eggs to cold in laboratory experiments

The number of eggs used in the different part-experiments varied between 400 and 1,300. The hatching percentage at room temperature was 95 to 100. The eggs were laid at 17—18° during the 4 days immediately prior to exposure. In experiments at temperatures below 0°, this included a preparatory reduction in temperature to between 0 and 4 degrees for 3 days, and a return to room temperature after exposure, similarly made by stages. Hatching was then checked for a period of four weeks.

The results are given in Table 10. The figures represent only complete hatching resulting in larvae fit for survival. The larvae were subjected to a thorough aftercheck in connection with the exposure of eggs for 7 days at —6°. All larvae from the surviving eggs grew normally, pupated and produced nor-

Table 10. Ephestia kühniella. Resistance in eggs to cold in laboratory experiments.

Tabell 10. Ephestia kühniella. Motståndskraft hos ägg mot kyla i laboratorieförsök.

Temperature, °C *Temperatur*		Days of exposure *Exponering, dagar*	hatched *kläckta %*
mean *medeltal*	daily fluctuations *dagliga fluktuationer*		
11.5	± 0.5	43	10
10	± 0.5	43	0
— 6	± 2.5	2 5 7	100 84.5 65
— 7.5	± 3	5 10	25 0.7
— 7	± 4	10	0
— 9.5	± 0.5	2 5 7	18 4.8 0
—18	± 0.5	1	0
—18.5	—	7 hours *7 timmar*	0

mally developed adults with normal reproduction powers.

As the table shows, the eggs died within 6 weeks at an exposure of +10°C. At a temperature as low as between —9 and —10°, a number of eggs had survived 5 days of exposure but not 7 days. Severe cold at —18 to —19° had a lethal effect within a few hours.

During experiments with 1-day-old eggs (= the stage of most resistance), Zacher, 1940, found that the percentage hatched after an 11-day exposure at —3.5 to —4°C was 0.5, and after 12 days 0.0. The eggs accounted for in Table 10 displayed a somewhat higher resistance in that some survived a 10-day exposure at a temperature fluctuating between —4.5 and —10.5°.

Resistance in pupae and larvae to cold in laboratory experiments

The material used in all experiments consisted of a 100-odd cocoons stuck to small pieces of corrugated cardboard and containing pupae and halfgrown and fully grown larvae. The material was selected from cultures on coarse wheat-flour kept at room temperature and a relative humidity of approximately 70%. As in the experiments with eggs previously described, the materiel was subjected to a gradual reduction in temperature. After finished exposure, the material was kept at room temperature for a control period lasting up to a month in some cases.

Table 11 shows, among other things, that both pupae and larvae were able to survive, with no deleterious aftereffects, a temperature fluctuating between —4 and —10° for 12, but not 15 days. Their maximum duration of life at —10° was roughly 5 days, and at —19° less than 24 hours.

Exposure to outdoor temperature in winter

A hut was used during these experiments which was built in such a way that the temperature inside it was practically the same as the outdoor temperature. Small pieces of sacking stuck together with lumps of flour containing large quantities of pupae and larvae were placed loosely scrunched-up in large glass tubes, 20 cms long and 7 cms in diameter, closed at both ends with wire gauze. After a preparatory temperature decrease to 5° lasting 24 hours, the tubes were transferred to the hut where they were kept horizontally placed on a detached platform about ½ metre above the floor.

A similar exposure covered the period Jan. 19th—27th, 1954. Severe cold prevailed during the major part of this 9-day period:

	Minimum	Maximum
January 19th	—11.5°C	—2.5°C
20th	— 9	1
21st	— 3	1.5
22nd	— 4	—1
23rd	—17	—3
24th	—12	—4
25th	—18	—4
26th	—18	—4.5
27th	—17	—6

Investigation of the material one week after finished exposure, and subsequent continued control, gave the following results. Of 447 larvae selected from the material, 40 were alive and 407 (=90%) dead. Most of the surviving larvae pupated within a month and gave normally developed adults. After 15 days 47 adults had emerged from an indefinite number of pupae and these were also normally developed with normally proceeding reproduction.

Protected by their cocoons but otherwise fully exposed to the open air, the pupae and larvae were thus able to survive several successive days with minimum temperatures of —17 to —18°C.

The result of a similar exposure during a 19-day period extending from Jan. 31st to Feb. 18th showed that, although quite high, their resistance to cold is evidently limited. During the first 13 days of exposure, temperatures differed greatly, varying between a minimum of —2 — —17° and a maximum

of +1 — 8°. Very severe cold prevailed during the last 5 days:

	Minimum	Maximum
February 14th	—23°C	—7°C
15th	—23	—9
16th	—13	—6
17th	—19	—7
18th	—11	—5

After this exposure, both pupae and larvae were dead without exception.

Overwintering in unheated buildings

Some paper sacks, each containing 25 kgs of larvae-infested coarse rye-flour, were kept in an unheated building in the vicinity of Stockholm during the period Sept. 24th, 1954—June 8th, 1955. Submerged deep in the flour in one of the sacks was a thermometer which was read 2 to 4 times a week.

The temperature of the flour, which was 17°C when the flour was laid in store and which had dropped to 8° by the beginning of October, then fluctuated between 2 and 4° during October—November and the main part of December. From Dec. 26th to April 19th inclusive, i.e. for an unbroken period of nearly 4 months, the temperature of the flour was constantly below 0°, except for the 8-day period from Jan. 31st to

Table 11. Ephestia kühniella. Resistance in pupae and larvae to cold in laboratory experiments.

Tabell 11. Ephestia kühniella. Motståndskraft hos puppor och larver mot kyla i laboratorieförsök.

Temperature, °C. *Temperatur*		Exposure, days *Exponering, dagar*	% dead *döda*		Footnotes *Fotnot*
mean *medeltal*	fluctuations *fluktuationer*		pupae *puppor*	larvae *larver*	
— 7	± 3	10	57	52	a)
		12	68	70	b)
		15	—	99	c)
		17	—	100	
— 9.5	± 0.3	7	100	100	
— 10	± 1	5	100	32	d)
		6	100	100	
— 19	± 0.5	1	100	100	

a) All surviving pupae gave normally developed adults. Of surviving larvae 55% gave normally developed adults, and 45% adults with stunted wings.

a) *Alla överlevande puppor gav normalt utvecklade fjärilar. Av de överlevande larverna gav 55 % normalt utvecklade fjärilar och 45 % fjärilar med förkrympta vingar.*

b) Of surviving pupae 15% gave normally developed adults, and 85% adults with stunted wings. Of surviving larvae 6% gave normally developed adults, 94% died before pupating.

b) *Av de överlevande pupporna gav 15 % normalt utvecklade fjärilar och 85 % fjärilar med förkrympta vingar. Av de överlevande larverna gav 6 % normalt utvecklade fjärilar, 94 % dog utan förpuppning.*

c) All surviving larvae died before pupating.

c) *Alla överlevande larver dog utan förpuppning.*

d) Of surviving larvae 97% died within 14 days after finished exposure, 3% pupated, but no adults emerged.

d) *Av de överlevande larverna dog 97 % inom 14 dagar efter avslutad exponering. 3 % förpuppades, men inga fjärilar framkläcktes.*

February 7th, during which time it fluctuated between 0 and 2°. The following extract from the temperature log shows the part-periods when the temperature in the flour was particularly low.

Period		No. of days	Temperature of flour °C
January	5—10	6	—3 to —4
	13	1	—8
	14—17	4	—3 to —5
	18—21	4	—8
February	13	1	—10
	14—15	2	—7
	16	1	—10
	17—19	3	—4 to —6
	20	1	—9
	21—22	2	—7
	23—24	2	—3
	25	1	—8
	26—Marsh 3	6	—3 to —6
Marsh	6—12	7	—3 to —6
	18—23	6	—6

As can be seen, there was an unbroken 9-day period of frost during January, at the end of which the temperature of the flour was down to —8° for four successive days. Still lower temperatures, —9 to —10°, were noted on several occasions during the 19-day period from Feb. 13th—March 3rd.

The mean air-temperatures in the district for the months December to March covering the experiment period were lower than normal. Below, the latter are given in parentheses:

1954	November	2.0°C	(1.6)
	December	—2.6	(—1.3)
1955	January	—2.7	(—2.5)
	February	—4.5	(—2.6)
	March	—2.7	(—0.4)

The sacks were inspected on June 8th 1955 and it was found that between 1 and 2% of the number of larvae present had survived. These larvae, all of which were found on the outer layer of the flour on the inside of the sacks, then pupated within 2 weeks when kept at room temperature, and gave normally developed adults.

The results show that, fairly far north in the country, larvae of *Eph. kühniella* are able to overwinter even in infested stores, which, through being kept in cold premises, have assumed a longlasting, low temperature below freezing-point.

Ephestia elutella Hb

This species is a common pest in Sweden and appears in chocolate factories and tobacco stores. On occasions it has been observed in stores of imported grain and fodder and also in colonial-produce.

Overwintering in unheated buildings at outdoor temperature

In October 1954, larvae of *Eph. elutella* were collected in a warehouse in the port of Stockholm, where they occurred in abundance on the outside of jute sacks containing imported oil cakes. An open glass jar with a 3—4-cm thick layer of ground wheat kernels together with paper strips, adhering to which were larvae spun in their cocoons, was kept from Dec. 27th 1954—April 13th 1955 in the hut mentioned in previous experiment reports.

The winter 1954/55 was somewhat colder than normal. The mean temperature in Stockholm during the three coldest months was as follows (normal temperatures given in parentheses):

1955	January	—2.7°C	(—2.5)
	February	—4.5	(—2.6)
	March	—2.7	(—0.4)

Fig. 6 shows the air-temperature at the test place during the aforementioned exposure period. It can be seen that

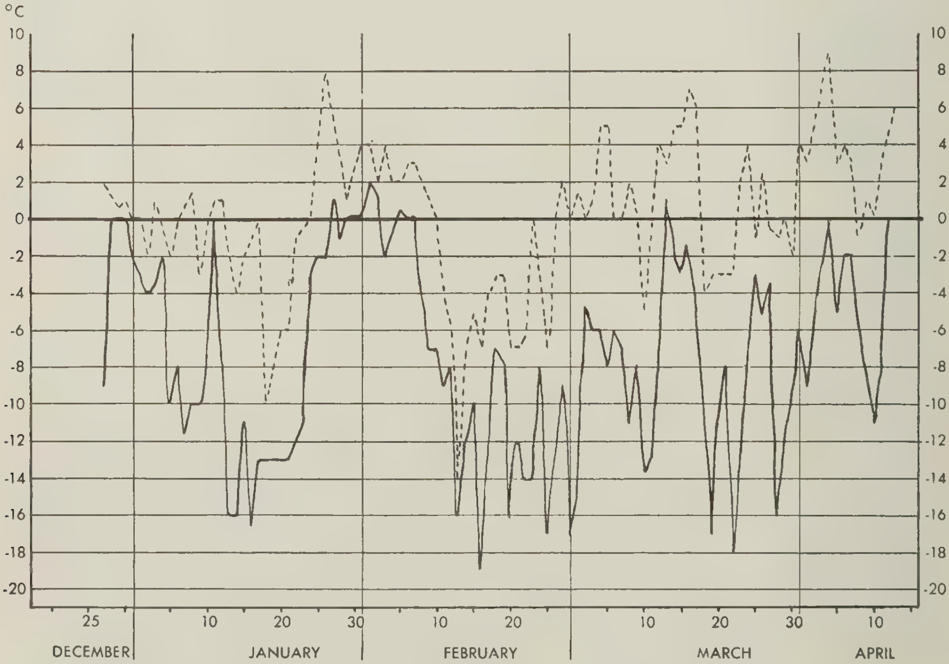

Fig. 6. *Ephestia elutella.* Minimum and maximum air-temperature during exposure to cold 27.12.1954—13.4.1955.

Fig. 6. *Ephestia elutella. Minimi- och maximitemperatur under exponering för kyla 27.12.1954—13.4.1955.*

there were periods of severe frost in January, February as well as in March. During 36 different days the minimum temperature was lower than —10°, and during 10 of these days lower than —15°. A minimum temperature of between —17 and —19° was recorded on 5 different days. It should also be noted that the *maximum* day temperature was —14° on Feb. 13th, a day which occurred during the first part of a continuous period of cold lasting 12 days, during which maximum temperatures were always far below zero.

A sample was taken out on Jan. 17th after an exposure period of 22 days, during which the minimum temperature recorded on 8 different days was between —10 and —16°, and all larvae were found to be alive. After a few days at room temperature they were fully lively.

At the end of the exposure period on April 13th, approximately 50% of the remaining larvae were alive. They were still living after 1½ months at room temperature, at which time, however, the material had to be discarded because of serious infestation by mites.

In the experiment described above, the larvae of *Eph. elutella* displayed such a high degree of resistance to cold that they can be considered capable of overwintering in the whole of central and southern Sweden, even in unprotected places in all types of unheated buildings.

Ephestia cautella Wlk

During an inspection made in January 1956 in a chocolate factory, which was reported as being seriously infested by moths, the dominating species was found to be *Eph. cautella;* the case was mentioned in a Swedish report to EMPPO, 1958. This species had not previously been found to be a pest of any importance in Sweden. Wahlgren, 1915, mentions only that *Eph. coutella* "is accidentally imported and found among oil cakes and on figs". With regard to the chocolate factory mentioned above, it should be pointed out that, 6 years earlier, it had similarly been seriously infested by moths, but the pests at that time were represented by *Eph. elutella* and, to a lesser degree, *Eph. kühniella.*

During the summers of 1956—58, there were further cases of an abundance of *Eph. cautella* appearing in some large long-term stores of imported oil cakes in sacks located in the southernmost part of Sweden. It was remarkable to note that these infestations were in progress after the cakes had been stored for 2—3 years in unheated warehouse premises.

Sømme, 1959, mentions *Eph. cautella* as being new to Norway in connection with an inventory made in the summer of 1958 of the occurrence of different stored product pests in Norway. The species "appeared to be a much more important pest in chocolate factories than *Ephestia elutella*".

The following contains a report on certain biological investigations carried out during the years 1956/58 with regard to the effect of temperature on *Eph. cautella* in different respects.

Reproduction and developmental period at various temperatures

Breeding experiments were carried out with the use of three different kinds of nourishment, namely whole wheat kernels, dried wheat germs and rolled oats, all with a moisture content of approximately 14.5%. New generations containing an abundance of specimens were produced throughout the year with all these three foods.

At room temperature, the females began laying eggs during the second day after they had emerged, and the laying period lasted about 5 days. A check kept on the egg production of 20 females revealed an average of 225 and a maximum of 406 eggs per female. The following table shows the shortest incubation period and the percentage of hatched eggs at various temperatures; the number of eggs in the different part-experiments varied between 200 and 1,000, and the material comprised a mixture of eggs from many different females:

Temperature °C.	Shortest incubation period days	Total hatched %
28	3	90
24	5	92
20	9—10	88
16 ±1	14	98
14 ±0.5	22	38
13.5±0.5	27	10
13	—	0

The shortest larva-period noted was 20—21 days at a temperature of 24.5° and 35 days at 21°.

When rearing on wheat germs, the shortest total developmental period from egg to adult was as follows:

Temperature °C.	No. of days minimum	
24.5±0.5	35—37	
21 ±0.5	57	(60 days when breeding in wheat)
18 ±1	76	(83 days when breeding in wheat)
15.5±1.5	115	
13.5±0.5	—	(no development of larvae)

In the experiments reported above, the lower temperature limit for both hatching of eggs and development of larvae was thus 13°; cf. BURGES, 1956.

In breeding experiments together with *Eph. kühniella*, the total developmental period was the same for both species at a temperature of about 20°, but 8 days shorter for *Eph. cautella* at 24.5°.

Exposure to outdoor temperature in winter

Infested material, consisting of matted lumps of wheat germs with pupae and larvae, was exposed to cold in the experimental hut for short periods during the winter 1956/57. The experiments were arranged in the same way as those described on page 31 in connection with *Eph. kühniella*.

The results of these experiments provided confirmation of the small degree of resistance to cold in this species found by several authors, including MANSBRIDGE 1936, SOLOMON & ADAMSON 1955, BURGES 1956.

Table 12 shows the temperatures during an exposure period of 22 days from Dec. 12th—January 2nd. It can be seen that the minimum temperature never dropped below zero during the first 9 days, and that the maximum temperature during the same period fluctuated between 4 and 9°. During the remaining 13 days the minimum temperature fluctuated between —2 and —6°, the maximum temperature between 5 and —3°. This moderate degree of cold was found to have been lethal to all pupae (approx. 100) and to all larvae (150 fully grown and a number of younger ones) in the exposed material.

A similar experiment was made which covered the 6-day period from January 9th—14th. The temperatures were as follows:

		Minimum	Maximum
January	9th	2°C	9°C
	10th	1	9
	11th	—2	3
	12th	—6	2
	13th	—5	—1
	14th	—7	—4

On inspection of the material four days after finished exposure, 25% of the larvae were found alive. During the course of the following 6 weeks, however, they died without exception. All pupae died within 14 days. Even from this short exposure, both pupae and larvae had thus suffered irreparable

Table 12. Ephestia cautella. Air-temperature in unheated building during exposure of infested material for 22 days.

Tabell 12. Ephestia cautella. Lufttemperatur i ouppvärmd byggnad under exponering av infesterat material i 22 dagar.

Day *Dag*		Temperature, °C. *Temperatur* min.	max.	Day *Dag*		Temperature, °C. *Temperatur* min.	max.
December	12.	1	5	December	23.	— 4	2
	13.	1	4		24.	— 5	— 3
	14.	0	4		25.	— 5	— 3
	15.	1	5		26.	— 4	— 1
	16.	3.5	6		27.	— 2	0
	17.	5	9		28.	— 6	0
	18.	3	9		29.	— 2	0
	19.	3	9		30.	— 4	0
	20.	0	5		31.	— 2	1
	21.	— 5	5	January	1.	— 3	1
	22.	— 2	2		2.	— 4	— 2

damage. It is probable that the injury occurred at quite an early stage of the exposure period. Supporting this theory is the fact that BURGES, 1956, found in laboratory experiments with freely exposed larvae of *Eph. cautella* that a 24-hour exposure to —1° was sufficient to cause the death of the larvae before any pupation had taken place.

Overwintering in unheated warehouses

As mentioned earlier, *Eph. cautella* has shown itself capable, despite its sensitivity to cold, of overwintering for several successive years in the southernmost part of Sweden in large stores of sacked products kept in unheated buildings. Generations abounding in adults and larvae have been observed during the summer months. The following table, which gives the mean temperature of the district (the town of Ystad) for the months November—March, shows that the winters of the period in question were no milder than normal.

BURGES, 1956, claims that "... the normal British winter is not likely to eliminate infestations of *E. cautella* completely in large bulks or stacks of produce in warehouses". The same evidently also applies to the southernmost part of Sweden.

	1953/54	1954/55	1955/56	Normal (1901—1930)
November	6.9°C.	4.4	4.9	4.5
December	3.3	3.6	1.7	1.9
January	—1.4	—1.1	—0.1	0.6
February	—3.2	—3.4	—6.7	0
March	0.7	—1.4	0.3	1.8

Summary

Introduction. For pests in grain and similar products which, as a rule, are stored in unheated buildings, the winter months constitute a more or less critical period, depending on the climate prevailing and the degree of resistance in these pests.

The climatic conditions in Sweden are such that grain and similar products in store during winter can usually be made to assume a comparatively low temperature. Table 1 shows how grain stored in deep layers during the cold season retains its low temperature practically unchanged the year round. The risk of large-scale infestation in such products may be regarded as negligible.

Among other things proving the importance of the temperature of vulnerable products when laid in store, with regard to the activity of existing pests, are the experiences acquired in connection with large-scale, prolonged storage, for emergency purposes, of bread grain and certain kinds of imported fodder which is practised in Sweden. In cases where for various reasons it has been necessary to lay up stores at a time of the year when the temperature of the product is comparatively high, more or less serious infestation has occurred on a considerably large scale some time after. In addition to *Laemophloeus ferrugineus*, several other species of heat-requiring insects have been found to cause the most serious damage, and these are insects which are not normally capable of surviving the winter in well cooled grain, such as *Sitophilus oryzae*, *Rhizopertha dominica* and *Oryzaephilus surinamensis*. Because of the heating accompanying infestation, the pests have been capable of mass reproduction even during the coldest winter months.

The main part of the present work is devoted to a report on certain studies made in order to investigate the dependence of various storage pests on the temperature of the surrounding media, especially their resistance to cold. Other subjects dealt with include the reproduction capacity of certain species at great depths in bulk grain, *Oryzaephilus surinamensis* as a primary pest, and weight losses in grain resulting from infestation by *Rhizopertha dominica.*

Sitophilus granarius L. This species is usually of less importance as a pest in the large, long-term stores of grain in Sweden than *S. oryzae*, *Rh. dominica* and flat grain-beetles. This is probably due to the fact that these other species have a greater chance of surviving and reproducing in a warm, dry medium. The temperature in infested grain becomes super-optimal for *S. granarius* at an early stage, while the moisture content becomes sub-optimal; investigations have revealed that the moisture content in warm, infested grain always drops from an original 13% to between 10 and 12%.

Table 2 contains the results of laboratory experiments performed to determine the resistance in *S. granarius* to cold. It can also be seen from the results given in Table 3 that the values obtained are higher throughout than those given in earlier published investigations made by various authors.

The resistance to cold has also been investigated in connection with experiments made by exposing adults together with developmental stages in grain to outdoor temperatures for certain periods during the winter months. Fig. 1 shows the temperature in the infested wheat during an exposure period covering the time from Oct. 8th 1958—January 10th 1959. It can be seen that, after the turn of the month October/November, the temperature of the wheat

remained almost constantly below 0°C, dropping periodically to between —9 and —12°. 5% of the adults survived, while all developmental stages had already been dead 1 month.

Fig. 2 shows the air-temperature during the exposure of adults and infested wheat to winter cold for a 57-day period from Oct. 26th—Dec. 21st 1955; for some of the beetles, the exposure time was extended to Feb. 2nd 1956. 8% of the adults survived the first period and these had been subjected to two periods of very severe cold, closely following and with minimum temperatures of —17 and —21° respectively for several days in succession. It seems evident that the resistance in *S. granarius* to pronounced falls in temperature of short duration in connection with exposure of this kind to fluctuating outdoor temperatures is considerably greater than appears from results of laboratory experiments at constant temperatures.

The said extension of the exposure period to Feb. 2nd 1956 in the last-mentioned experiment resulted in 100% mortality. The results of this experiment and of other similar experiments show that although the resistance in *S. granarius* to cold is quite considerable, it is by no means unlimited.

Sitophilus oryzae L. Compared to *S. granarius*, the resistance to cold in *S. oryzae* is very low. Fig. 3 shows the air-temperature in an unheated building in which small amounts of wheat containing adults and developmental stages of both species were kept during the period from Nov. 13th 1942—March 24th 1943. Despite the fact that the temperature never dropped below 0°C, all *S. oryzae* were dead as early as Jan. 14th, while *S. granarius* were still living at the end of the exposure period. In a similar experiment, both species were exposed to outdoor temperature during the period from Dec. 1st—21st 1959, the temperature of the wheat being that given in Fig. 4. *S. oryzae* died out, while mortality in *S. granarius*, on the other hand, remained at about 60%.

Rhizopertha dominica F. Investigations have revealed that this species, as is the case with *S. oryzae* and flat grain-beetles, can survive and reproduce at considerable depths, 4—5 metres, in bulk grain. Moreover, both adults and developmental stages of the species display a remarkably high tolerance to the high temperatures arising in grain as a result of infestation; see Table 4.

An estimation of the extent of damage, which was made as a wheat store was being infested by *Rh. dominica*, revealed that the direct weight loss resulting from feeding on the kernels averaged 3.5% in an infestation site containing between 300 and 400 tons of wheat.

As is shown by parallel experiments performed with *S. granarius* and summarized in Table 5, the resistance in *Rh. dominica* to cold is low. The species is capable, however, of surviving short periods of cold, and this was confirmed by an experiment in which infested wheat was exposed to outdoor temperatures during the period from November 5th 1957 to January 10th 1958. A sample was taken on Dec. 12th, i.e. after 37 days of exposure, and it was found that 4.5% of the adults had survived, despite the fact that the temperature of the wheat dropped to between —6 and —8° on certain days, as shown in Fig. 5. However, in new samples of wheat taken on Jan. 2nd and 10th, both adults and developmental stages were all dead.

Laemophloeus ferrugineus Steph. In connection with infestation of grain stored over long periods in Sweden, this species is the most commonly occurring of all. Confirmation of its being a primary pest in this connection has been provided on many different occasions.

In breeding experiments carried out with the species, a temperature fluctuating between 15 and 17° was the lowest at which *L. ferrugineus* was able to

carry through its development from egg to adult. In the case of grain stored in deep layers, an initial temperature corresponding to the aforementioned would probably suffice to permit a gradual increase in the number of individuals, which is due to accumulation of the heat developed in connection with the activity of adults and larvae.

The resistance to cold is fairly high, especially in the developmental stages. These latter proved capable of surviving the entire 67-day period, summarized in Fig. 5, in infested wheat, which, through exposure to winter cold, had at times assumed a temperature of —6 to —12°C. It has been shown, however, that *L. ferrugineus,* as is the case with *S. granarius,* is capable of surviving the winter months in exposed surroundings, such as empty storage buildings, only in the southern areas of Sweden.

Oryzaephilus surinamensis L. Direct experiments and investigations of infested stores have shown the species to be a primary and heat-developing pest in grain.

Breeding experiments have revealed that the minimum temperature for pupation and development of larvae is between 17 and 18°C, in other words, fairly high. A further ½ to 1 degree of temperature is required for developing adults capable of reproduction; see Table 7.

The resistance to cold is evidently less than in *S. granarius* and *L. ferrugineus;* for example, cf. table on page 23 and figures in Tabl. 2 and 6. Acording to experiments performed, however, *O. surinamensis,* too, is capable of overwintering in southern and central Sweden in grain stored in deep layers.

Trogoderma granarium Everts. This species has appeared only occasionally as a pest in Sweden, more specifically in imported shipments of grain and oil cakes.

Biological investigations have revealed that *T. granarium* could scarcely be expected to become stationary as a storage pest in Sweden, mainly because of the fact that as high a temperature as 20—25°C is the minimum required for reproduction in the species. The larvae take in no nourishment at temperatures below 15° but possess great resistance to starvation. 50% of the larvae included in a breeding experiment were still alive after having been kept at a temperature fluctuating between 4 and 12° for a period of 17 months. Experiments have shown that the larvae remain immobile at temperatures below 6.5°.

The resistance to cold in the larvae is exceptionally high. In exposure experiments at constant temperatures, a certain percentage of larvae were thus able to survive —2° for 180 days, —5.5° for 90 days, —10° for 30 days and —19° for 10 days; cf. Table 8. Similarly, numerous larvae survived an unbroken period, covering two winters and the intervening summer period, in a small quantity of wheat kept in a hut where the temperature was practically the same as that outdoors. Table 9 shows that several periods of severe frost occurred during both these winters.

Ptinus tectus Boield. In Sweden, this species has been observed mainly as a pest in imported oil cakes.

In southern Sweden at least, the species has no difficulty in overwintering, even in cold storage premises. Laboratory experiments have confirmed that both adults and larvae possess a considerable degree of restistance to cold. In experiments with constant temperatures, 30% of adults survived a 30-day exposure at —5°C. Approximately 50% of the larvae survived an exposure first covering a 60-day period at 0°, which was immediately followed by a 45-day period at —5°. The long exposure of the larvae at 0° resulted in an increase in the resistance to the subsequent period of more severe cold, which was confirmed by the fact that larvae, which had been transferred to —5° after only

a few days' preparatory reduction in temperature to between +12 and +4°, died without exception within 50 days.

Ephestia kühniella Zell. Tables 10 and 11 contain the results of laboratory experiments performed to determine the resistance in eggs, larvae and pupae to cold. Among other things, it can be seen that the eggs are capable of surviving exposure at —9 — —10° C for 5 but not for 7 days, and that a temperature of between —18 and —19° has a lethal effect on all developmental stages in less than 24 hours.

Investigations into the degree of resistance have also been carried out in connection with exposure to outdoor temperatures during winter periods of frost. Protected by their cocoons but otherwise fully exposed to the open air, the pupae and larvae showed themselves capable of surviving several successive days with minimum temperatures of —17 to —18°. At temperatures of between —20 and —25°, however, all had died within a few days.

Storage experiments have shown that the larvae of *Eph. kühniella,* at least in southern and central Sweden, are able to overwinter in infested stores, which, through being kept in cold premises, have assumed a longlasting, low temperature below freezing-point.

Ephestia elutella Hb. In Sweden this species is a common pest in chocolate factories and tobacco stores. It has also been observed on occasions in stores of imported wheat.

The capacity of the larvae to overwinter in cold surroundings was investigated during the winter 1954/55 in connection with the storage of larvae-containing material (crushed wheat kernels in thin layers) in a hut where the temperature was the same as that outside. Fig. 6 shows the air-temperature at the site during the exposure period Dec. 27th 1954—April 13th 1955. It can be seen that there were periods of severe frost in January, February as well as in March. At the end of the exposure period it was found that 50% of the larvae had survived. The larvae of *Eph. elutella* apparently possess a sufficient degree of resistance to cold to enable them to overwinter, at least in the whole of central and southern Sweden, even in unprotected places in all kinds of unheated buildings.

Ephestia cautella Wlk. The first time this species was observed as an important pest in Sweden was in 1956 in a chocolate factory. The same year and later, cases were reported of the species occurring in great numbers during the summer in long-term stores of imported oil cakes located in southernmost Sweden.

Eph. cautella, in its capacity of a storage pest new to Sweden, has been subjected to certain biological investigations mainly concerning the influence of the temperature factor in different respects. In the experiments described below, dried wheat germs were used as breeding material; new generations containing an abundance of specimens were produced throughout the year also with the use of whole wheat kernels and rolled oats.

Mating occurred within a few hours at room temperature and egg-laying began during the second day after emergence of the adults. On inspection of the total egg production of 20 fecundated females, an average of 225 and a maximum of 406 eggs per female were noted. The incubation period for the eggs varied between 3 days at 28° and 27 days at 13.5°C. Neither hatching of eggs nor development of larvae occurred at temperatures below 13°.

The shortest larva-period was 20—21 days at 24.5° and 35 days at 21°. The shortest total development time from egg to imago varied between 35—37 days at 24.5° and 115 days at 15.5°.

The resistance to cold was low, in sharp contrast to the high degree of resistance which characterizes the closely related species *Eph. kühniella* and *Eph.*

elutella. Serving to illustrate this is the fact that larvae and pupae of *Eph. cautella* were dead without exception after exposure of infested material for 22 days to the comparatively slight degree of cold shown in Table 12. However, despite its proven low degree of resistance to cold, the species has shown itself capable of overwintering in the very southernmost parts of Sweden for several successive years in large, compact stores of bagged oil cakes.

Sammanfattning

Studier över viktigare förrådsskadedjur i Sverige, med avseende främst på motståndskraften mot låg temperatur.

Inledning. De kosmopolitiskt spridda förrådsskadedjuren kännetecknas generellt sett av en begränsad motståndskraft mot kyla, låt vara att avsevärda skillnader i detta hänseende råder mellan olika arter. Speciellt för skadedjur i spannmål och liknande produkter, vilka ju i regel förvaras i ouppvärmda byggnader, är vinterhalvåret följaktligen en mer eller mindre kritisk period allt efter det rådande klimatet och graden av deras motståndskraft.

I Sverige är klimatförhållandena sådana, att spannmål och andra produkter under lagring vintertid i regel kan bibringas en jämförelsevis låg temperatur. Tabell 1 exemplifierar, hurusom spannmål, som inlagrats i djupa skikt under den kalla årstiden, sedermera bibehåller sin låga temperatur praktiskt taget oförändrad året om. Riskerna för insektsangrepp av större omfattning i en sådan vara kan betraktas som obetydliga.

Den väsentliga roll, som inlagringstemperaturen spelar för befintliga skadedjurs aktivitet i stora upplag av angripbara produkter, framgår bl. a. av erfarenheterna i samband med den omfattande långtidslagring av brödspannmål och vissa importerade kraftfodermedel för beredskapsändamål, som förekommer i Sverige. I de fall, där man av olika anledningar varit nödsakad att verkställa inlagringen vid en årstid, när varans temperatur varit jämförelsevis hög, cirka 20°, har mer eller mindre starka insektsangrepp efter någon tid inträffat i betydande utsträckning. Förutom brungula plattbaggen, *Laemophloeus ferrugineus,* har flera värmekrävande insektsformer, vilka normalt ej förmår att övervintra i väl nedkyld spannmål, varit de svåraste skadegörarna i dylika sammanhang. Hit hör sålunda risviveln, *Sitophilus oryzae,* kapucinbaggen, *Rhizopertha dominica,* och sågtandade plattbaggen, *Oryzaephilus surinamensis.* På grund av den värmeutveckling, som städse följer med angreppen, har skadedjuren varit i stånd att massföröka sig även under de kallaste vintermånaderna.

Som en metod att i bekämpningssyfte utnyttja de aktuella insektsformernas mer eller mindre utpräglade känslighet för låg temperatur har i Sverige under de senaste åren med rätt stor framgång tillämpats aktiv luftgenomblåsning och kylning av angripna spannmålslager med hjälp av transportabel specialapparatur. En redogörelse för metoden är under utarbetande i och för publicering.

I föreliggande arbete redogörs huvudsakligen för vissa undersökningar över olika förrådsskadedjurs beroende av det omgivande mediets temperatur, främst motståndskraften mot kyla. Därjämte berörs även fortplantningsförmågan hos vissa arter på stora djup i löst lagrad spannmål, sågtandade plattbaggens *(Oryzaephilus surinamensis)* egenskap av primärt skadedjur i hel säd, ävensom viktsförluster i spannmålslager genom angrepp av kapucinbagge *(Rhizopertha dominica).*

Kornviveln, *Sitophilus granarius L.* Som skadedjur i långtidslager av spannmål i Sverige är denna art i regel av mindre betydelse än risviveln, kapucinbaggen och plattbaggarna. Anledningen härtill torde vara den, att dessa andra arter har större förmåga än kornviveln att fortleva i ett varmt och torrt medium. Temperaturen i angripen spannmål blir på ett tämligen tidigt stadium överoptimal och i många fall slutligen även letal för kornviveln och dess utvecklingsstadier, samtidigt som vattenhalten blir underoptimal.

I tabell 2 återges resultat av laboratorieförsök över kornvivelns motståndskraft mot kyla. Som framgår av sammandrag i tabell 3 är de erhållna värdena genomgående högre än de som angivits i tidigare publicerade undersökningar av skilda auktorer.

Köldhärdigheten har även undersökts i samband med att kornvivlar jämte deras utvecklingsstadier inuti spannmålskärnor exponerats för ytterluftens temperatur periodvis under vinterhalvåret. Fig. 1 återger temperaturen i angripet vete under en exponeringsperiod, som omfattade tiden 8.10.1958—10.1.1959. Som synes låg vetets temperatur efter månadsskiftet oktober/november praktiskt taget ständigt under 0° och sjönk periodvis ned till —9 à —12°. Av de fullbildade skalbaggarna överlevde 5%, under det att alla utvecklingsstadier var döda redan 1 månad före exponeringsperiodens slut.

Fig. 2 återger lufttemperaturen i samband med exponering av kornvivlar för vinterkyla under 57-dagarsperioden 26.10—21.12.1955; för en del av skalbaggarna utsträcktes exponeringstiden till den 2.2.1956. Den förstnämnda perioden överlevdes av 8%. Som framgår av fig. hade dessa kornvivlar varit utsatta för tvenne tätt på varandra följande delperioder med mycket sträng kyla, med minimitemperaturer på —17 resp. —21° under flera dygn i följd. Tydligt är, att kornvivelns motståndskraft mot kortvariga starka temperaturfall i samband med dylika exponeringar för en fluktuerande yttertemperatur är avsevärt större än vad som framgår av olika uppgifter, baserade på laboratorieförsök vid konstanta temperaturer.

Den i det senast relaterade försöket nämnda förlängningen av exponeringsperioden för en del av försöksdjuren till den 2.2.1956 medförde 100% dödlighet. Kornvivelns motståndskraft mot kyla är visserligen betydande men dock ingalunda obegränsad. Som ett belägg härför kan för övrigt påpekas, att kornviveln, vad lantgårdarnas spannmålsmagasin beträffar, förekommer stadigvarande endast i landets sydliga delar. I skyddet av stora spannmålslager, förvarade i djupa skikt, förmår kornviveln däremot övervintra även uppe i mellersta Sverige.

Risviveln, *Sitophilus oryzae* L. I jämförelse med kornviveln har risviveln en ringa motståndskraft mot kyla. Fig. 3 återger lufttemperaturen i en ouppvärmd lokal, i vilken smärre poster av vete, innehållande skalbaggar jämte utvecklingsstadier av båda arterna, förvarades under perioden 13.11.1942—24.3.1943. Trots att lufttemperaturen ej vid något tillfälle understeg 0° var risviveln utdöd redan den 14.1., under det att kornviveln fortlevde under hela exponeringsperioden. I ett annat liknande försök exponerades båda arterna för ytterluftens temperatur under perioden 1.12.—21.12.1959, varvid vetets temperatur var den i fig. 4 återgivna. Risviveln utdog, medan däremot dödligheten hos kornviveln stannade vid ca 60%.

Kapucinbaggen, *Rhizopertha dominica* F. Undersökningar har visat, att denna art, liksom för övrigt även risvivel och plattbaggar, fortplantar sig utan svårighet även på så stort djup som 4—5 meter i löst lagrad spannmål. Vidare har såväl den fullbildade skalbaggen som utvecklingsstadierna en anmärkningsvärt stor tolerans mot de höga temperaturer, som blir rådande i angripen spannmål; se tabell 4.

En beräkning av skadegörelsens omfattning, som vid ett tillfälle gjordes i anslutning till ett pågående angrepp av kapucinbagge i ett vetelager, gav till resultat, att den direkta viktsförlusten genom gnag på kärnorna var i genomsnitt 3,5% inom en angreppshärd, omfattande mellan 300 och 400 ton vete.

Kapucinbaggens motståndskraft mot låg temperatur är tämligen ringa, vilket belyses av det i tabell 5 redovisade försöket med kornvivel som jämförelseobjekt. Att kapucinbaggen dock är i stånd att överleva åtminstone kortare perioder av kyla framgick av ett försök.

vari angripet vete exponerades för ytterluftens temperatur under perioden 5.11.1957—10.1.1958; se fig. 5. Vid uttagande av prov från vetet den 12.12., alltså efter 37 dagars exponering, befanns nämligen 4,5% av skalbaggarna ha överlevt, trots att vetets temperatur under vissa dygn hade varit nere i —6 à —8°. I nya prov av vetet, som sedermera uttogs den 2.1. och 10.1., var dock såväl skalbaggar som utvecklingsstadier undantagslöst döda.

Brungula plattbaggen, *Laemophloeus ferrugineus* Steph. I samband med insektsangrepp i långtidslagrad spannmål i Sverige är denna art den allmännast förekommande. Dess egenskap av primärt skadedjur i dylika sammanhang har vid upprepade tillfällen kunnat verifieras.

I uppfödningsförsök har en temperatur, fluktuerande mellan 15 och 17°, varit den lägsta, vid vilken arten varit i stånd att fullborda hela utvecklingen från ägg till skalbagge. När spannmål under längre tid lagras i djupa skikt, torde en initialtemperatur av nyssnämnda höjd vara tillräcklig för en småningom inträdande och allt starkare ökning av individantalet hos denna art, detta på grund av ackumulering av den värme, som utvecklas i samband med skalbaggarnas och larvernas aktivitet.

Motståndskraften mot låg temperatur är betydande, speciellt hos utvecklingsstadierna. Dessa var i stånd att överleva hela den i fig. 5 återgivna 67-dagarsperioden i angripet vete, som genom exponering för vinterkyla bibringats en temperatur av tidvis —6 à —12°. Det har emellertid visat sig, att brungula plattbaggen, i likhet med kornviveln, endast i de sydliga delarna av landet kan överleva hela vinterhalvåret i för kyla exponerad miljö, exempelvis i tömda lagringslokaler.

Sågtandade plattbaggen, *Oryzaephilus surinamensis* L. Artens egenskap av primärt uppträdande och värmealstrande skadedjur i spannmål har fastslagits såväl vid direkta försök som genom undersökningar av angripna lager.

Av uppfödningsförsök har framgått, att minimitemperaturen för larvutveckling och förpuppning ligger mellan 17 och 18°, alltså tämligen högt. För frambringande av fortplantningsdugliga imagines krävs f. ö. ännu ½ à 1 grader högre temperatur; jfr tabell 7.

Motståndskraften mot låg temperatur är påtagligt lägre än hos exempelvis kornvivel och brungul plattbagge; jfr sammanställning på sidan 23 med uppgifterna i tabellerna 2 och 6. I skyddet av spannmålslager, som förvaras i djupa skikt, är sågtandade plattbaggen dock, enligt vad utförda försök visat, i stånd att övervintra i hela södra och mellersta Sverige.

Khaprabaggen, *Trogoderma granarium* Everts. Denna art har endast tillfälligtvis uppträtt som skadedjur i Sverige, närmare bestämt i importerade partier av spannmål och oljekakor.

Biologiska undersökningar har lett till den slutsatsen, att khaprabaggen sannolikt saknar förutsättningar att bli stationär som förrådsskadedjur i Sverige. Bl. a. ligger minimitemperaturen för fortplantning så högt som mellan 20 och 25°. Larverna upptar ingen föda vid temperaturer, understigande 15°, men har mycket stor motståndskraft mot hunger. Av larver, som förvarades vid en temperatur, fluktuerande mellan 4 och 12°, fortlevde sålunda i ett uppfödningsförsök 50% ännu efter 17 månader. Larverna förblir orörliga, så snart temperaturen understiger 6.5°.

Khaprabaggens larver har utomordentligt stor motståndskraft mot kyla. I exponeringsförsök vid konstanta temperaturer var sålunda en viss procent av larverna i stånd att överleva —2° i 180 dagar, —5.5° i 90 dagar, —10° i 30 dagar och —19° i 10 dagar; jfr tabell 8. Likaså överlevde talrika larver en sammanhängande period, omfattande två vintrar jämte mellanliggande sommarhalvår, i en mindre kvantitet vete, som förvarades i en uthusbyggnad med en

temperatur praktiskt taget lika med ytterluftens. Av tabell 9 framgår, att flera perioder med sträng kyla förekom under båda dessa vintrar.

Australiska tjuvbaggen, *Ptinus tectus* Boield. I Sverige har denna art huvudsakligen uppmärksammats som skadedjur i importerade oljekakor.

Åtminstone i södra Sverige övervintrar australiska tjuvbaggen utan svårighet även i kalla magasinslokaler. Laboratorieförsök har bekräftat, att såväl skalbaggen som larven har en betydande motståndskraft mot kyla. Sålunda överlevde skalbaggar en 30-dagarsexponering vid —5°. I ett försök med larver överlevde ca 50% en exponering, vilken omfattade dels en 60-dagarsperiod vid 0°, dels omedelbart därefter en 45-dagarsperiod vid —5°. Att den långvariga exponeringen av larverna för 0° verkade stegrande på deras motståndskraft mot den efterföljande starkare nedkylningen framgick av att larver, som efter endast några dagars förberedande temperatursänkning till mellan +12 och +4° överfördes till —5°, undantagslöst dog inom 50 dagar.

Kvarnmottet, *Ephestia kühniella* Zell. I tabellerna 10 och 11 har sammanställts resultat av laboratorieförsök över utvecklingsstadiernas motståndskraft mot låg temperatur. Av uppgifterna framgår bl. a., att äggen kan överleva exponering för —9 à —10° i 5 men ej i 7 dygn, samt att —18 à —19° verkar dödande på alla utvecklingsstadier inom kortare tid än 1 dygn.

Undersökningar över motståndskraften har gjorts även i samband med exponering för yttertemperatur under köldperioder vintertid. I skyddet av sina spånader och kokonger men i övrigt exponerade för den fria luften har puppor och larver därvid visat sig vara i stånd att bl. a. överleva flera på varandra följande dygn med minimitemperaturer på —17 à —18°. Vid exponering för köldgrader på mellan —20 och —25° har de dock dött inom få dagar.

Genom anordnade lagringsförsök har klarlagts, att kvarnmottets larver åtminstone i södra och mellersta Sverige är i stånd att övervintra i angripet gods, såsom säckar med mjöl, som genom lagring i kalla lokaler bibringats en för lång tid bestående låg temperatur, understigande fryspunkten.

Hömottet eller kakaomottet, *Ephestia elutella* Hb. Denna art är även i Sverige ett vanligt skadedjur i chokladfabriker samt i tobakslager. Vid enstaka tillfällen har den även uppmärksammats i lager av importerat vete.

En undersökning över larvernas övervintringsförmåga i kall miljö utfördes vintern 1954/55 i samband med förvaring av larvbemängt material (krossade vetekärnor i tunt skikt) i en uthusbyggnad med samma temperaturförhållanden som ute i det fria. Fig. 6 återger lufttemperaturen på platsen under exponeringen, vilken omfattade perioden 27.12.1954—13.4.1955. Som synes förekom delperioder med mycket sträng kyla under både januari, februari och mars månader. Vid exponeringsperiodens slut befanns ca 50% av larverna ha överlevt. Tydligen har alltså hömottets larver så stor motståndskraft mot kyla, att de åtminstone i hela södra och mellersta Sverige kan övervintra även i oskyddat läge i ouppvärmda byggnader av varje slag.

Mandelmottet, *Ephestia cautella* Wlk. Denna art, som tidigare saknat svenskt namn, bör lämpligen kunna kallas »mandelmottet», efter eng. »the Almond Moth».

Som en skadeinsekt av betydelse uppmärksammades mandelmottet i Sverige första gången år 1956, närmare bestämt i en chokladfabrik. Samma år och även sedermera konstaterades förekomst av individrika populationer av arten sommartid även i några långtidslager av importerade oljekakor i sydligaste Sverige.

I sin egenskap av ett för Sverige nytt förrådsskadedjur har mandelmottet varit föremål för bl. a. vissa biologiska

undersökningar, vilka huvudsakligen berört temperaturfaktorns inflytande i olika hänseenden. Som näringssubstrat har i de här nedan återgivna försöken använts torkade vetegroddar.

Vid rumstemperatur skedde parning inom några timmar och begynte äggläggningen under andra dygnet efter fjärilarnas framkläckning. Vid kontroll av 20 befruktade honors totala äggproduktion noterades per hona ett medelantal av 225 och ett maximiantal av 406 ägg. Kläckningstiden för äggen varierade mellan 3 dagar vid 28° och 27 dagar vid 13.5°. Vid temperaturer, understigande 13°, skedde ingen kläckning av ägg, ej heller någon larvutveckling.

Som kortvarigaste larvperiod noterades 20—21 dagar vid 24.5° och 35 dagar vid 21°. Den kortaste sammanlagda utvecklingstiden från ägg till imago varierade mellan 35—37 dagar vid 24.5° och 115 dagar vid 15.5°.

Motståndskraften mot kyla var låg, detta i stark kontrast till den betydande köldhärdighet, som utmärker de närbesläktade formerna kvarnmott och hömott. Så t. ex. var larver och puppor av mandelmottet undantagslöst döda efter exponering av angripet material i 22 dygn för den i tabell 12 återgivna, jämförelsevis obetydliga kylan. Trots sin dokumenterat ringa köldhärdighet har arten dock visat sig vara i stånd att i den sydligaste delen av landet övervintra flera år i följd i stora och kompakta lager av säckade oljekakor, förvarade i ouppvärmda lagerhus.

References

Back, E. A. & Cotton, R. T., 1924. Relative resistance of the Rice Weevil, *Sitophilus oryzae* L., and the Granary Weevil, *S. granarius* L., to high and low temperatures. — J. agric. Res., 28. Washington.

Burges, H. D., 1956. Some effects of the British climate and of constant temperatures on the life-cycle of *Ephestia cautella* (Walker). — Bull. ent. Res., 46. London.

Cotton, R. T., 1956. Pests of stored grain and grain products. Minneapolis, Minn.

Dendy, A. & Elkington, H. D., 1920. Rept. Grain Pests (War) Committee, Royal Soc., no. VII. London.

Europ. and Mediterr. Plant Prot. Org. (Emppo), 1958. Pests and diseases of foodstuffs in store 1955—1957. Paris.

Freeman, J. A., 1951. Pest infestation control in breweries and maltings. — Journ. Inst. Brewing, LVII., No. 5 (XLVIII., New Series). Cambridge.

— , & Turtle, E. E., 1947. Insect pests of food. The control of insects in flour mills. Ministry of Food. London.

Hadaway, A. B., 1956. The biology of the Dermestid beetles, *Trogoderma granarium* Everts and *Trogoderma versicolor* Creutz. — Bull. ent. Res., 46. London.

Howe, R. W., 1956. The biology of the two common storage species of *Oryzaephilus* (Coleoptera, Cucujidae). — Ann. Appl. Biol., 44, No. 2. Cambridge.

— , & Burges, H. D., 1953. Studies on beetles of the family Ptinidae. IX. A laboratory study of the biology of *Ptinus tectus* Boield. — Bull. ent. Res., 44. London.

Kirchner, H.-A., 1940. Versuche über den Einfluss der Winterkälte auf den Kornkäfer *(Calandra granaria* L.). — Nachr. blatt d. Deutsch. Pfl.sch.dienst, 20, Nr. 1. Berlin.

Kosmina, N. P., 1956. Organisation und Technik der Getreidelagerung. Deutscher Bauernverlag. Berlin.

Mansbridge, G. H., 1936. A note on the resistance to prolonged cold of some insect pests of stored products. — Proc. R. ent. Soc. Lond., A, 11. London.

Mathlein, R., 1938. Kornviveln, *Calandra granaria* L., och risviveln, *Calandra oryzae* L. — Statens växtskyddsanstalt, Meddelande n:r 23. Stockholm.

— , 1959. Erfahrungen über Vorkommen und Bekämpfung von Schädlingen in schwedischen Dauerlagern von Brotgetreide. — Ges. f. Vorratsschutz: Beitr. z. V.sch.forsch.anlässl. d. 75 Geb. tages Prof. Dr. F. Zacher. Berlin.

Solomon, M. E. & Adamson, B. E., 1955. The powers of survival of storage and domestic pests under winter conditions in Britain. — Bull. ent. Res., 46. London.

Sømme, L., 1959. *Ephestia cautella* (Wlkr.) (Lep., Pyralidae), new to Norway. — Norsk Entom. Tidskr., XI, 1, 2. Oslo.

Ushatinskaja, R. S., 1948. (In Russian). The importance of sudden and gradual falls of temperature on the cold stability of the Granary Weevil *(Calandra granaria* L.). Zool. Zh., 27.

— , 1950 a. (In Russian). Resistance to cold of grain weevils *Calandra granaria* and *Sitophilus oryzae*. — Bull. Acad. Sci. U. R. S. S., (Biol.).

— , 1950 b. (In Russian). The influence of the humidity of the surroundings and of food on the cold resistance of the Granary Weevil, *Calandra granaria*. — Zool. Zh., 29.

Wahlgren, E., 1915. Svensk Insektfauna, 10, II. Uppsala.

Zacher, F., 1940. Wie wirkt der Frost auf die Vorratsschädlinge? — Mitt. Ges. Vorratsschutz, Nr. 2. Berlin.